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POPULATION DYNAMICS AND PRODUCTION OF THE AMPHIPOD COROPHIUM SA--ETC(U)
SEP 81 R ALBRIGHT, D A ARMSTRONG DACW67-80-C-0091

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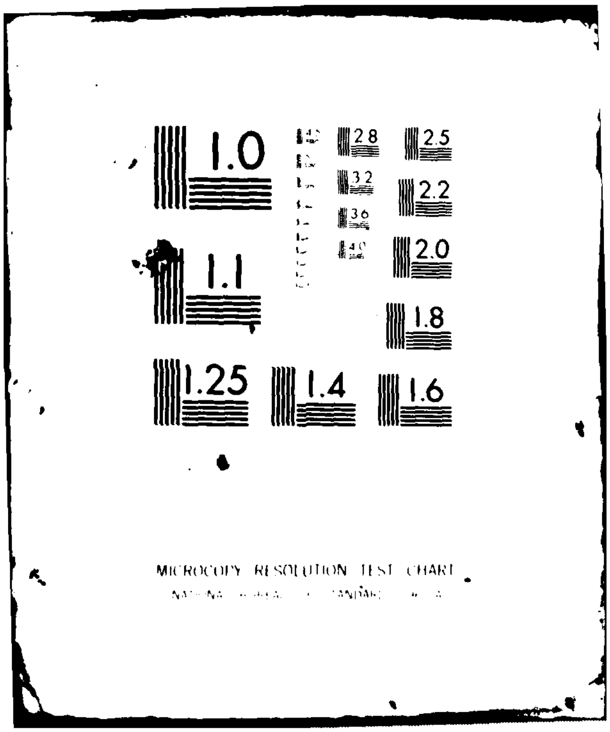
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GRAYS HARBOR AND CHEHALIS RIVER
IMPROVEMENTS TO NAVIGATION
ENVIRONMENTAL STUDIES

COROPHIUM SPP. PRODUCTIVITY IN GRAYS HARBOR, WASHINGTON

PREPARED BY:

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UNIVERSITY OF WASHINTON AND
WASHINGTON DEPARTMENT OF GAME

JANUARY 1982

US Army Corps of Engineers
Seattle District

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A113 215	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Population dynamics and production of the Amphipod Corophium salmonis in Grays Harbor, Washington		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Richard Albright David A. Armstrong		8. CONTRACT OR GRANT NUMBER(s) DACW67-80-C-0091
9. PERFORMING ORGANIZATION NAME AND ADDRESS School of Fisheries University of Washington Seattle, WA 98195		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Seattle District US Army Corps of Engineers P.O. Box C-3755 Seattle, WA 98124		12. REPORT DATE September 1981
		13. NUMBER OF PAGES 63
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Washington Game Department Olympia, Washington 98504		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

AMPHIPODA
POPULATION
AQUATIC PRODUCTIVITY
BENTHIC FAUNA
GRAYS HARBOR
WASHINGTON (STATE)
COROPHIUM SALMONIS
MUD FLATS
ESTUARIES
FISH FOOD ORGANISMS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The tube-dwelling amphipod Corophium salmonis is a dominant benthic organism and important food resource in the estuarine mudflats of Grays Harbor, Washington. Intertidal core samples were collected at two sites during the spring and summer of 1980 to determine the population structure, biomass, rate of growth and production of C. salmonis. Two elevations (+1.8 and +.6 meters relative to MLLW) were sampled at each site.

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C. salmonis abundance ranged from 0 to 49,700 individuals per m^2. Peak abundances occurred during July and August. Abundances at the 1.8 meter stations were higher than at the .6 meter stations.

Female *C. salmonis* attained sexual maturity as a length of 4.0-4.5 mm. Brooding of eggs began in April and continued through the end of sampling (Septemer 30). Eggs hatched after 2-3 weeks of brooding during spring.

Male-female ratios were lower for sexually mature *C. salmonis* than for immature *C. salmonis*, apparently as a result of predation on sexually mature males which wander over the tideflats in search of females. Male-female ratios decreased in the lower intertidal, and at all stations decreased throughout the sampling period. An inverse relationship between male-female ratios for mature and immature *C. salmonis* suggests a possible genetic response to disparate sex ratios among mature individuals.

Data from both natural populations and from cohorts artifically isolated inside *in situ* cages were used to obtain size-specific growth rate curves and production estimates from *C. salmonis*. Total *Corophium* production for each station between April 1 and September 30 varied from 3.6 to 10.7 grams dry wt. per m^2. *Corophium* production was higher at the upper intertidal stations. Turnover rates (the ratio of production to mean biomass) ranged from 7.2 to 8.6.

Corophium salmonis production and turnover rates indicate that this amphipod provides a substantial food source for its predators. The proposed widening and deepening of the navigation channel in Grays Harbor should have little impact on *C. salmonis*. However, another species of *Corophium*, *C. spinicorne*, which is abundant in the navigation channel near Cosmopolis, may be significantly impacted. The possible disposal of dredge materials on intertidal tideflats represents the greatest potential impact to *C. salmonis*.

COVER PHOTOGRAPH: Preparing the experimental *Corophium* cages.

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Population Dynamics and Production of the Amphipod *Corophium salmonis* in Grays Harbor, Washington

by

Richard Albright

and

David A. Armstrong

TECHNICAL REPORT TO:

Washington Game Department

and U.S. Army Corps of Engineers

September 1981

CONTRACT NO. DACW67-80-C-0091

Data, interpretations, and conclusions in this report are those of the authors.

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ACKNOWLEDGEMENTS

Special thanks are due Steven Kalinowski, Jack Howerton, Patricia Bouthillette and Gene McKeen of the Washington State Game Department; Steven and Jack for their support, advice and help regarding project management, and Pat and Gene for their many hours of help in the field and lab. A variety of other people also provided valuable help in the field and lab, including Paul LaRiviere, Mark Pirak, Angela Kost, Annamaria Escofet, Joshua Fasoranti, and Larry Cooper. Angela and Annamaria also gave freely of ideas and suggestions which helped improve the quality of this report.

Drs. Ron Thom and John Armstrong of the U.S. Army Corps of Engineers, Seattle District, contributed valuable comments and suggestions throughout the planning, field sampling, and data analysis phases of this report.

The employees of the College of Fisheries Business Office (including Ben Hayes and Gwen Bromgard) deserve recognition also. Their continual assistance and incredible patience with our blunderings through the administrative mazes of budget management, purchasing procedures, payroll policies, hiring procedures, etc., etc., etc., were absolutely critical to the functioning of this project. Rosemary Frost and Karen Fisher of the University of Washington Stenographic Service Bureau, and Valery Munzlinger of the Aquaculture and Invertebrate Fisheries Division, School of Fisheries, did an outstanding job of typing the manuscript.

The research performed on this project was supported by a subcontract from the Washington State Game Department. The Game Department, in turn, received their funds from the U.S. Army Corps of Engineers,

Seattle District, as part of Phase I of the Environment Impact Studies related to the proposed widening and deepening of the navigation channel in Grays Harbor, Washington.

ABSTRACT

The tube-dwelling amphipod Corophium salmonis is a dominant benthic organism and important food resource in the estuarine mudflats of Grays Harbor, Washington. Intertidal core samples were collected at two sites during the spring and summer of 1980 to determine the population structure, biomass, rate of growth and production of C. salmonis. Two elevations (+1.8 and +.6 meters relative to MLLW) were sampled at each site.

C. salmonis abundance ranged from 0 to 49,700 individuals per m^2. Peak abundances occurred during July and August. Abundances at the 1.8 meter stations were higher than at the .6 meter stations.

Female C. salmonis attained sexual maturity at a length of 4.0 - 4.5mm. Brooding of eggs began in April and continued through the end of sampling (September 30). Eggs hatched after 2-3 weeks of brooding during spring.

Male-female ratios were lower for sexually mature C. salmonis than for immature C. salmonis, apparently as a result of predation on sexually mature males which wander over the tideflats in search of females. Male-female ratios decreased in the lower intertidal, and at all stations decreased throughout the sampling period. An inverse relationship between male-female ratios for mature and immature C. salmonis suggests a possible genetic response to disparate sex ratios among mature individuals.

Data from both natural populations and from cohorts artificially isolated inside in situ cages were used to obtain size-specific growth rate curves and production estimates for C. salmonis. Total Corophium production for each station between April 1 and September 30 varied from 3.6 to 10.7 grams dry wt. per m^2. Corophium production was higher at the upper intertidal stations. Turnover rates (the ratio of production to mean biomass) ranged from 7.2 to 8.6.

Corophium salmonis production and turnover rates indicate that this amphipod provides a substantial food resource for its predators. The proposed widening and deepening of the navigation channel in Grays Harbor should have little impact on *C. salmonis*. However, another species of *Corophium*, *C. spinicorne*, which is abundant in the navigation channel near Cosmopolis, may be significantly impacted. The possible disposal of dredged materials on intertidal tideflats represents the greatest potential impact to *C. salmonis*.

INTRODUCTION

The importance of estuaries as feeding and nursery areas for commercially and recreationally important fish and wildlife has become widely accepted. Prior studies in Grays Harbor (USACE, 1976) have indicated that this estuary is no exception, having substantial populations of waterfowl, shorebirds, salmon, English sole, starry flounder, harbor seals, and Dungeness crabs (Albright, 1977). In view of this, the U.S. Army Corps of Engineers funded a number of studies on the physical and biological characteristics of Grays Harbor for the purpose of identifying potential impacts resulting from proposed dredging to widen and deepen the navigation channel. Included were studies on bird, fish, Dungeness crab, and crangonid shrimp populations, food habit studies, and determination of the abundance and distribution of benthic (bottom-dwelling) invertebrates in the current navigation channel and on adjacent tideflats.

Few of the benthic invertebrate species present in Grays Harbor's 22,000 hectares are (or could potentially be) of commercial value. However, the primary importance of the benthos to humans is as a food resource for economically valuable species. As such, the benthos provides a critical component of estuarine habitats. Studies of the benthos can therefore provide a measure of the quality of the estuarine environment for economically valuable species which feed upon benthic invertebrates either directly or indirectly (i.e., by feeding on other predators using benthic invertebrates as prey). Benthic invertebrate distributions and abundances provide a more precise measure of the health of an environment than other animal groups as they usually are either immobile or move over relatively small areas. Thus they tend to survive or not survive in a particular location, lacking for the most part the ability to emigrate to more suitable surroundings. Studies which go beyond surveys of the distributions and abundances of benthic

invertebrates, such as determination of growth rates, production [the rate of incorporation of organic matter or energy (Crisp, 1971)], and turnover rates (the ratio of production to mean biomass) can be of value in quantifying the importance of benthic food resources to their predators and the magnitude of impacts resulting from human activities. However, such studies of benthic communities are expensive and difficult. Much of the cost and difficulty can be eliminated by emphasizing the study of key species known to be dominant members of the benthic community and important prey for economically important species. Warwick (1980) provides support for this concept, stating that the majority of benthic community production is supplied by a very few dominant species.

Prior benthic sampling in Grays Harbor during 1974-75 (Albright and Rammer, 1976) showed the tube-dwelling amphipod *Corophium salmonis* (incorrectly referred to as *C. stimpsoni* by the authors) to be one of the dominant benthic macroinvertebrates in the mud and muddy-sand environments of the inner half of Grays Harbor. Albright and Rammer (1976) found densities of up to 57,000 per m^2, and gut content analysis showed *C. salmonis* to be an important food organism for Dunlin, English sole, and starry flounder (Smith and Mudd, 1976; Bengston and Brown, 1976). In addition, *C. salmonis* is eaten by juvenile salmon, Pacific tomcod, sculpins, stickleback, and occasionally waterfowl (Bengston and Brown, 1976; Kalinowsky, Martin and Cooper, 1981). Several invertebrates, such as the shrimp *Crangon franciscorum* and *C. nigricauda*, and Dungeness crab (*Cancer magister*) also feed on *C. salmonis* to varying degrees. Studies of other comparable Pacific Northwest estuaries have shown similarly high densities of and predation upon *C. salmonis* (Smith, 1977, 1980; Higley and Holton, 1975).

These studies, however, have only investigated the density and standing stock of *C. salmonis* at any one particular moment. The rate of growth

and reproduction of C. salmonis is unknown, thus no estimate of turnover rate, or the amount of organic matter available to predators through time, can be made. The amount of organic matter available for "harvest" by predators may be very different from the standing stock. The small size (normally $\leq$ 6.5 mm) of C. salmonis combined with high rates of predation upon this amphipod imply that the annual production of C. salmonis may be several times higher than the standing stock, providing a greater yield as a food resource than mere figures of standing stock would indicate.

The objectives of this portion of the Grays Harbor Navigation Channel Widening and Deepening Studies were to:

1) Examine the population structure and biomass of C. salmonis
2) Determine the rate of growth of C. salmonis
3) Estimate the production of C. salmonis at a proposed salt marsh establishment site and an adjacent control site.

It was felt that accomplishment of these objectives would provide the necessary information to quantitatively estimate the value of C. salmonis as a food resource to predators. This would enable a more accurate assessment of the impacts resulting from environmental alterations (e.g., channel widening and deepening, dredged material disposal) in Grays Harbor. Population data for C. salmonis could also be compared with population data for selected predators to determine possible correlations.

METHODS AND MATERIALS

STATION LOCATIONS

Two sites were chosen for the *Corophium salmonis* growth rate and population structure studies (Figure 1). The first, designated as Site M, was located along the south shore of Grays Harbor ($123^{\circ}51'10''$W, 46'57'5"N), and was a site proposed for the establishment of a salt marsh using sediments dredged from the main navigation channel. The second site designated Site MC) was located approximately 3 km west of Site M ($123^{\circ}54'14''$W, $49^{\circ}56'14''$N). At each site, stations were placed at +1.8 and +0.6 meters above mean lower low water (MLLW) and marked with either metal or wood stakes. Elevations at Site MC were set according to readings from a Port of Grays Harbor tide guage located at Terminal 1 in Aberdeen. Elevations at Site M were originally set with a hand held Berger level, using as a datum a reference marker established just upland of the mudflat by U.S. Army Corps of Engineers surveyors. On April 30, 1980, stations at Site M were re-measured using a Zeiss level with an accuracy of $\pm$ 0.1 cm. It was found that the station elevations had been erroneously measured and that the original "+1.8" and "+0.6" meter stations were actually located at +1.5 m and +0.4 m respectively. Stations were then moved to the proper tidal elevation. During this and the subsequent two sampling trips, samples were collected at both the old and relocated stations to determine whether population structure and densities differed. After May 15, 1980, all samples were collected at the corrected tidal heights.

SEDIMENT SAMPLES AND SALINITY

The *C. salmonis* sampling stations are designated in this report by a number followed by one or two letters. The number refers to the height above MLLW at which the station was located, while the letter(s) refer to the site.

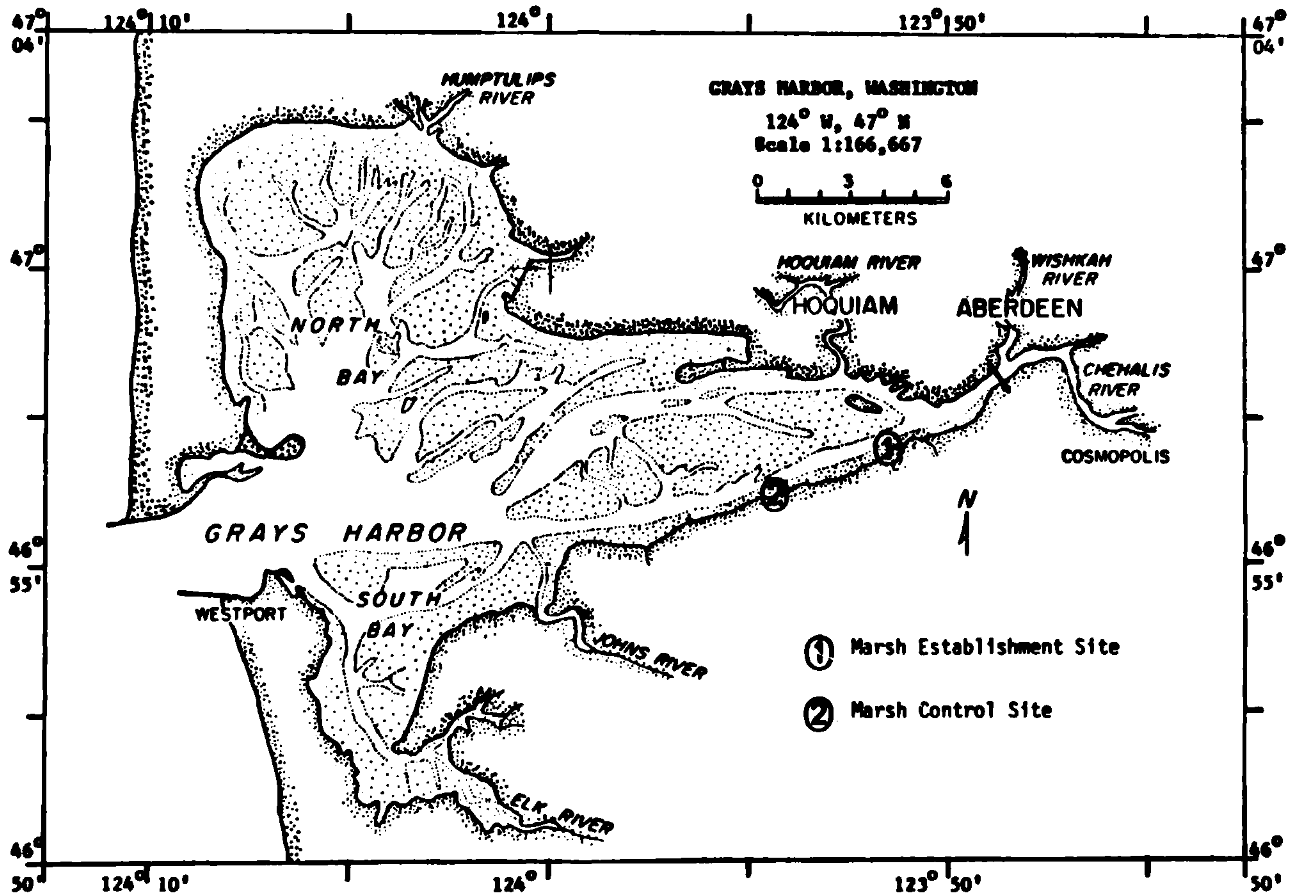

Figure 1: Location of study sites M and MC, Grays Harbor, Washington, 1980.

For example, the +.6 meter station at Site M is designated as .6 M.

Sediment samples were collected at each station in both May and August, 1980, for determination of grain size and percent of total volatile solids. Samples were obtained from randomly selected locations along a six meter transect placed parallel to the shoreline, with the station marker location at the center of the transect. Samples were collected using a section of PVC pipe with an inside diameter of 4.1 cm. Samples for grain size analysis were collected to a depth of 8 cm; samples for volatile solids analysis were collected to a depth of 3 cm. The actual analyses for grain size and percentage of volatile solids were performed by Drs. J. B. Phipps and E. D. Schermer of Grays Harbor College. For a summary of methods, see Appendix A. Procedures for grain size analysis followed those of Krumbein and Pettyjohn (1938). Results were reported as percent composition for each of the following sediment fractions: gravel (>2000μm), coarse sand (2000-500 μm), fine sand (500-62 μm), silt (62-4 μm) and clay (<4 μm). Results of the volatile solids analysis were reported as the percentage of mass loss following ignition in a muffle furnace at 550°C for one hour.

Salinity measurements were taken during each sampling trip. Samples were collected both from the water's edge at low tide, and from a small hole dug near the sampling station. The hole was dug to a depth of 4-8 cm and was constructed with a mud barrier around the opening which prevented surface water from flowing into the hole. Thus, water collected in the hole was primarily interstitial in origin, except during heavy rains.

POPULATION STRUCTURE AND GROWTH RATE

Core samples of surface sediments were collected at each of the sample stations to determine the population structure and growth rate of *C. salmonis*.

Sample cores were identical in size to those collected for grain size analysis (see previous section). This depth was sufficient to collect all *Corophium* species within the sediment. Seven randomly placed sample cores were collected along a six meter transect centered on the station marker and parallel to the shoreline. Samples were collected at one to two week intervals between March 12 and May 28, 1980, and between August 1 and September 26, 1980.

IN SITU GROWTH RATE IN CAGES

C. salmonis age classes (or cohorts) could no longer be distinguished from one another by late summer and early fall as a result of continuous breeding and the overlapping of generations. Thus a series of cages were used to obtain information on rates of growth during this period (Birklund, 1977). Cages were 46 cm long x 31 cm wide x 36 cm high, and were anchored in place with 76 cm long corner stakes. Two 1.5 m rebar stakes were placed at diagonal corners of the cages to provide additional anchoring. When pushed into the sediment, the top of the cages stood 15-20 cm above the sediment surface.

Cages were originally covered with 300 μm mesh Nitex netting for a period of 1-2 weeks. This mesh size was large enough to allow juvenile *C. salmonis* (~0.8 to 1.0 mm in length) to pass through the netting and settle into the sediment bounded by the cages. This time interval served as a "recruitment" period. After recruitment, the original netting was replaced with a 149 μm mesh netting, which prevented all *C. salmonis* from entering or leaving the cages. In essence, a cohort of *C. salmonis* was isolated inside each cage.

In August, 1980, a total of 36 cages were set at Site M, 18 each at +1.8

and +0.6 meters. Before placing the cages on the tideflat, the top 5-8 cm of sediments were scraped away to ensure removal of C. salmonis inhabiting that spot. Core samples were taken and analyzed to confirm the complete removal of C. salmonis in several test plots. Subsurface sediments from adjacent mudflats were added to the area where surface sediments had been removed to bring the elevation up to the level of the surrounding mudflats. While these subsurface sediments were quite anoxic when originally placed, such sediments oxidize quickly and can be colonized by C. salmonis in a matter of days (Eckman, 1979).

Three core samples were collected from two randomly selected cages at each tidal height at the time the 300 μm mesh netting was removed. These samples were used to determine the initial size of the recruited individuals. No core samples were taken within 5 cm of the edge of the cages to reduce any type of "edge effect" (any enhancement or retardation of growth rates which may have been caused purely by proximity to the sides of the cages). Core samples were collected from two cages at each elevation each week. Any cages which were "contaminated" or "invaded" by adult C. salmonis due to undercutting by water movement were not sampled. This was only a problem at the +1.8 m station. Figure 2 illustrates the time scheme for sampling of the growth cages.

SAMPLE PROCESSING

Core samples were initially preserved in a ten percent solution of formalin buffered with sodium carbonate. After sieving through a 300 μm mesh sieve, the retained material was stained for at least 24 hours in a solution containing the vital stain rose bengal, which stains organic matter a pink color. Although live juveniles were capable of crawling through a 300 μm mesh net, sieving of dead C. salmonis with this mesh size retained virtually all individuals. Sorting of Corophium species from the sieved

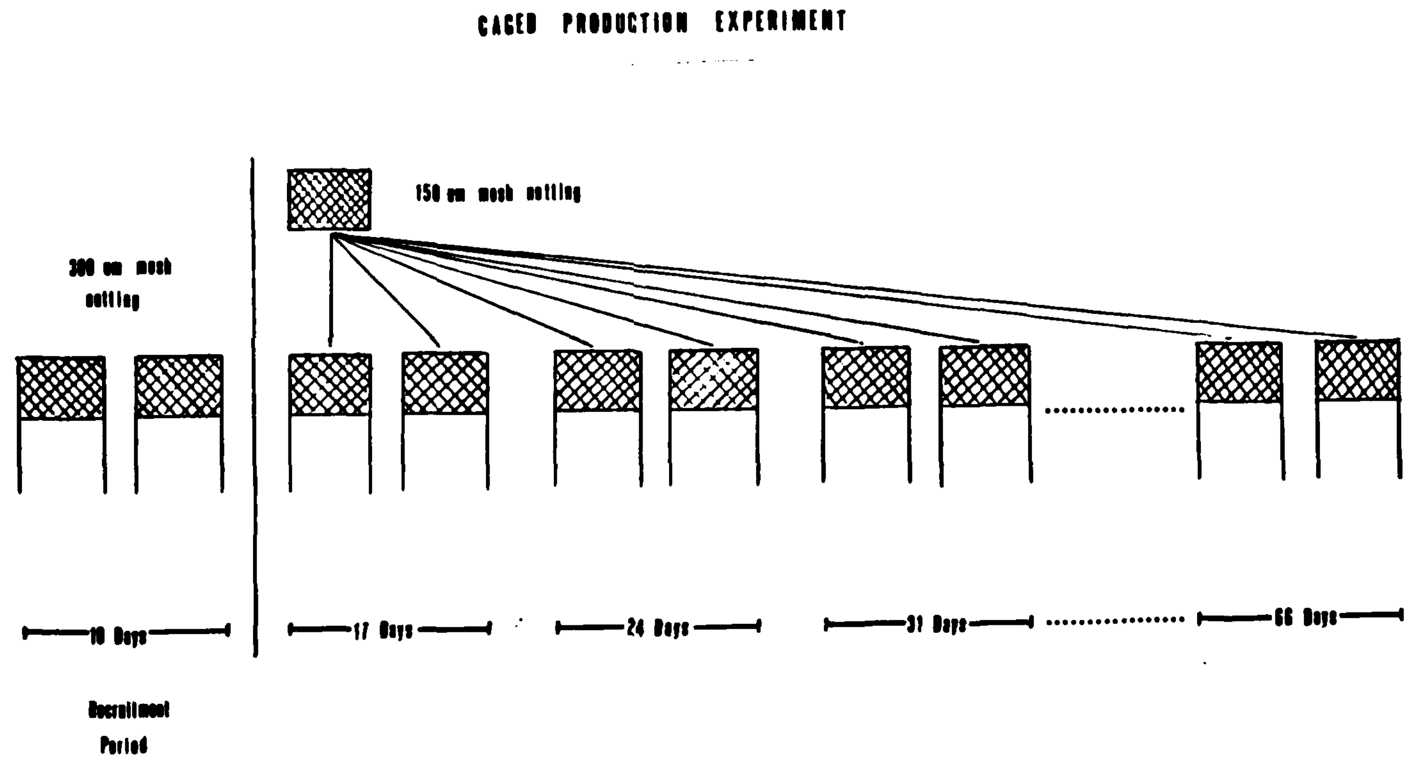

Figure 2: Time scheme for sampling of C. salmonis growth cages, Grays Harbor, Washington, 1980.

material was accomplished by floating specimens free from debris (Anderson, 1959). A sucrose solution with a specific gravity of 1.12, in which most of the sieved material (e.g. vegetation, wood debris, and fecal pellets) sank, while the Corophium species (as well as many of the other organisms) floated, was used to perform this separation. The technique worked so well for Corophium species that animals very often became trapped at the surface by water tension, and thus would float indefinitely. Corophium species were then scooped from the surface and preserved in a solution of 70 percent ethyl alcohol and five percent glycerol.

Individual Corophium were identified to species, sexed, and measured to length. Species identifications were made according to Otte (1975), with the additions that configuration of spines on the basal segment of antennal 1 and distance between basal segments of antennal 1 (viewed dorsally) were also used to aid in identification. Three species of Corophium were present in the study area; C. salmonis, C. spinicorne, and C. brevis.

Lengths (in mm) were measured from the tip of the rostrum to the tip of the telson using a calibrated eyepiece micrometer. Individuals were then assigned to 0.5 mm size classes.

Sex could only be accurately determined for C. salmonis 2.0 mm in length or larger, as prior to attaining this length the characteristics used to distinguish the sexes were not fully developed. Sex determinations were based on the configuration of spines on antenna II and the presence or absence of oostegites (structures which form a pouch used for brooding of eggs). For females greater than 2.0 mm in length, the stage of development of the oostegites was recorded in relation to the size of the adjacent gill, and the presence or absence of setae on the oostegite (characteristic of fully developed oostegites) was noted. In those cases where several stages of development

of oostegites were noted on the same individual, an average stage was recorded. The presence of eggs in the brood pouch of females was noted. Eggs were counted and their length measured along the longest axis. The stage of development of the eggs was also recorded on a scale of 1 to 5 as follows: Stage 1, egg an undifferentiated mass of cells; Stage 3, segmentation of embryo is visible, appendages forming, but not fully developed; Stage 5, appendages fully developed, eyes present. Stages 2 and 4 were used for intermediate stages of development.

Biomass (dry weight) was related to length using regression analysis. Separate regression analyses were performed for each sex (since there is marked sexual dimorphism in C. salmonis) as well as for season (spring and summer). Sixty-eight individuals representing the entire range of sizes encountered for each sex for both spring and summer were dried for 24 hours at 60°C before being weighed individually on a Cahn electro-balance (Model 4700).

The general form of the equation chosen to represent the length-weight relationship was that of a power curve as follows:

$$W = b \cdot L^{m}$$

where W is weight in mg, L is length in mm, and b and m are coefficients. The equation was then linearized to the form,

$$\ln(W) = \ln(b) + m \cdot \ln(L)$$

so that simple linear regression analysis could be performed.

PRODUCTION

Production of C. salmonis (i.e., the rate of incorporation of organic matter per unit area by C. salmonis, excluding the formation of sex products) was calculated according to the method of Crisp (1971). Data extracted from length-frequency histograms were used to construct a curve of age-specific

(actually size-specific) growth rates, using the equation:

$$G = \frac{d \ln \text{Weight}}{dt}$$

where G = size specific growth rate

d ln Weight = change of ln weight

dt = change in time.

This curve was used in computing production as follows:

$$\text{Production} = \sum^{t} \sum^{n} \sum^{s} f_i \, G_i \, \bar{w}_i \, \Delta t$$

where, t = time (in years)

n = number of size classes

s = sex

f_i = number of individuals in a particular size class/sex combination

G_i = size-specific growth rate for a particular size class/sex combination

$\bar{w}_i$ = mean individual weight for the size class/sex combination

Δt = time period (in years).

Average population densities used in the calculation of production were computed by size-class for each station. Average densities were calculated separately for time intervals between April 1 and September 30 during which overall population density and structure were similar. The average density at station 1.8 M during April was actually determined from samples collected at station 1.5 M. Densities at station .6 M for April and May were based on data collected at both stations .6 M and .4 M. The similarity in population density and structure between these stations justified combining their data. In addition, the contribution towards total production during these time periods at the Site M stations was relatively small compared to contributions later in the growing season.

RESULTS

SITE DESCRIPTIONS

Both Sites M (the Marsh Establishment Site) and MC (the Marsh Control Site) were located in the inner half of Grays Harbor along the southern margin of the bay. Site M was located approximately 200 m west of the mouth of Newskah Creek. Being the easternmost of the two study areas, Site M lay closer to the major sources of pollution in Grays Harbor, including a Weyerhaeuser Company pulp mill effluent settling basin .5 km to the east. The location of Site MC 3 km west of Site M likely resulted in the dilution of industrial and sewage pollutant levels relative to Site M. Site MC was bordered at its upper margin by a strip of salt marsh 10 to 20 m in width, consisting of a diverse plant community (primarily *Potentilla pacifica*, *Deschampsia cespitosa*, *Festuca rubra*, *Plantago maritima*, *Juncus* sp., *Hordeum* sp., *Carex lyngbyei*, *Glaux* sp., *Distichlis spicata*, and *Salicornia virginica*). At the edge of the marsh was a one meter dropoff to the mudflat. The upper mudflat had a moderate cover of eelgrass (mostly *Zostera noltii*) down to approximately +1.5 m. Beyond that point, the mudflat was largely devoid of vegetation. During spring, summer, and early fall, the tideflat had a substantial growth of benthic diatoms and green filamentous algae, mostly in the portion of the tideflat where eelgrass was present.

Site M was bounded at its upper edge by rip-rap adjacent to a railroad track. Some salt marsh was present adjacent to the rip-rap, especially at the western half of the Site. The marsh consisted of several patches of *Carex lyngbyei* and higher elevation, more diverse strips of marsh similar in species composition to the Site MC marsh. Two species of eelgrass (*Zostera marina* and *Z. noltii*) were present on the tideflats above 1.4 meters. Eelgrass cover was comparable in density to Site MC. Benthic diatoms and benthic algae were present, especially in the upper intertidal areas.

Table 1. Salinity measurements taken at Sites M and MC. Sample location numbers refer to elevation above MLLW.(W) refers to samples collected at the water's edge. (S)refers to samples collected from pools of standing seawater on the tideflats. Grays Harbor, Washington, 1980-81.

SALINITY MEASUREMENTS*

DATE

Site	Type of Sample	Sample Location	3-12-80	3-19-80	3-26-80	4-2-80	4-9-80	4-10-80	4-16-80	4-23-80	4-30-80	5-7-80	5-8-80	5-14-80	5-21-80	5-28-80	7-11-80	8-1-80	8-8-80	8-9-80	8-15-80	8-22-80
SITE M	Inter-stitial	.4 M .6 M 1.5 M 1.8 M	4	5		4 9		3	3 8		10 8	10	13 12	14 12		13 13 12	19	20 25	22 20	24	21 23	19 20
SITE M	Overlaying water	M(W) M(S)	2	0	6	4	6	3	2	4	6	13	8	10		11		17	20		21	22
SITE MC	Tidepool Inter-stitial	.6 MC 1.8 MC				13		15	15 13	13 11	14 13	20 16		14 19		15 16	17 22	20 26	19 26		26	22 24
SITE MC	Overlaying water	MC(W) MC(S)			6	10		6	7	5	14	17		14		14	20	24			22	22

Site	Type of Sample	Sample Location	8-29-80	9-5-80	9-11-80	9-22-80	9-26-80	10-7-80	11-21-80	11-22-80	1-20-81	2-15-81	3-24-81	4-6-81	4-20-81	5-5-81	5-19-81	6-2-81	6-3-81	6-16-81	6-30-81
SITE M	Inter-stitial	.4 M .6 M 1.5 M 1.8 M	25	21	22 22		21					8	13	6		5	8		15	10	8
SITE M	Overlaying water	M(W) M(S)	24	18	18	15	17	15		2		0	3	2	6	2	10 12	14	12 15	6 9	10 11
SITE MC	Tidepool Inter-stitial	.6 MC 1.8 MC	28 27	22 24	23 24		22 24		11				18	12	12	9	11	15		13	12
SITE MC	Overlaying water	MC(W) MC(S)	25	20	22		22		8			1	13	4	9	4	11 17	15 18		8 12	12 14

*Measurements in parts per thousand.

Because Site M was located closer to the mouth of the Chehalis River than Site MC, Site M had lower salinity values (Table 1). Salinities ranged from 0 to 25 parts per thousand (ppt) at Site M and 1 to 28 ppt at Site MC. The mean difference between sites for salinity measurements collected from the water's edge was 3.2 ppt (s.d. = 2.6). The mean difference in interstitial salinity at the 1.8 m stations was 3.8 ppt (s.d. = 1.6), while for the .6 m stations the difference was only 1.5 ppt (s.d. = 1.4). During periods when salinities were at the extreme upper or lower ends of the range, however, differences in salinity measurements between the two sites were usually less than when salinities were closer to midrange values. From March through April of 1980, salinity of interstitial water at both sites averaged about 9 ppt, reflecting high seasonal rainfall. During August and September, interstitial salinity was consistently over 20 ppt.

Analysis of sediment composition consisted of both grain size analysis and percent volatile solids (Table 2). Results of the grain size analyses showed all the stations to be highly similar in sediment size composition. Sediments at all stations consisted primarily of silt (67-82 percent). The percent of volatile solids was also similar for all stations, with the following exceptions: 1) values at .6 M were lower than values at other stations during both spring and summer of 1980, and 2) values at .6 MC were considerably higher in the spring of 1980 only. During summer, values at .6 MC decreased to levels comparable to those of other stations.

The low percentage of volatile solids at .6 M and the high percentage occurring at .6 MC in spring corresponded to differences in the compactness of the sediments at these stations. At Site M, the sediment at the .6 meter station was extremely compact, with a 1-3 cm layer of soft silt and clay on the surface. It was possible to walk on the sediment surface while sinking only through the soft surface layer of silt and clay. At Site MC, however,

Table 2. Comparisons of sediment composition at Sites M and MC, Grays Harbor, Washington, 1980.

		SIZE FRACTION (WEIGHT PERCENT)				PERCENT VOLATILE SOLIDS	
Station	Date	Course Sand	Fine Sand	Silt	Clay	Repl. #1	Repl. #2
.4 m	5-28		3.2	78.7	18.1	8.33	6.49
.6 M	5-28		8.7	75.3	16.0	5.84	5.89
	8-8	0.2	11.2	75.1	13.5	4.90	4.85
1.5 M	5-28		20.9	67.3	11.7	6.99	6.27
1.8 M	5-28		7.9	78.6	13.5	8.38	8.39
	8-8	0.4	14.9	71.0	13.7	7.85	6.94
.6 MC	5-28		9.8	82.3	7.9	9.46	12.20
	8-9		6.3	75.7	18.0	6.60	6.94
1.8 MC	5-28		8.1	80.2	11.7	7.70	6.71
	8-9		7.1	77.6	15.2	8.27	7.36

the sediments were extremely soft and unconsolidated at the .6 meter station, with the top few millimeters of sediment forming an unstable, soup-like layer. Project personnel were noted to sink a full meter into the sediment while attempting to walk near the station marker. The 1.8 meter stations at both sites were quite similar in compactness.

There was a significant difference biologically between stations .6 M and .6 MC. Station .6 MC had very few *C. salmonis* present, while a substantial population occurred at station .6 M. It is likely that the unstable sediments at .6 MC made construction of permanent or semi-permanent *C. salmonis* tubes unfeasible. In addition, the loosely packed sediments may have incorporated organic matter into the substrate more efficiently than hard packed sediments, resulting in a higher percentage of total volatile solids. This in turn may have discouraged colonization and/or growth of *C. salmonis* by creating more anoxic conditions. The firmly packed sediments at .6 M provided a more favorable substrate for construction of *C. salmonis* tubes, in addition to incorporating less organic matter into the sediments. The firm substrate may also have helped protect *C. salmonis* from predation.

POPULATION STRUCTURE AND REPRODUCTION

Density

Densities of *Corophium salmonis* at the study stations (excluding station .6 MC) varied between 216 and 49,675 individuals per m^2 (Figure 3). The highest density occurred at station 1.8 M on July 11, 1980. The density of *C. salmonis* at station .6 MC was too low to obtain any meaningful information on population structure, reproduction, growth rates, or production, thus data for this station is deleted from the remainder of the data analysis.

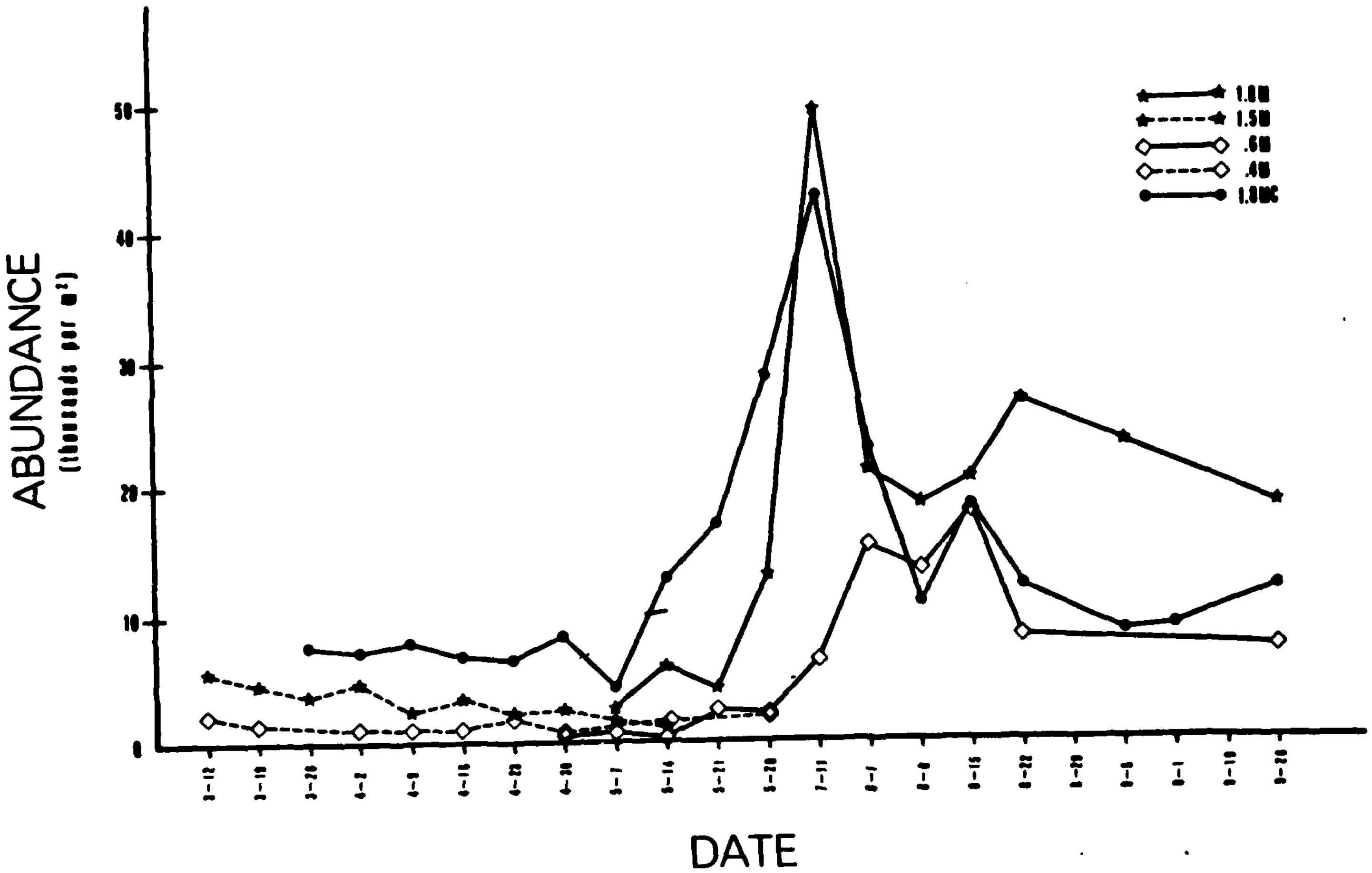

Figure 3: Mean population densities by date for sample stations at Sites M and MC, Grays Harbor, Washington, 1980. Note discontinuities along time axis preceding and following July 11 sampling date.

During spring of 1980, station 1.8 MC had the greatest abundance of *C. salmonis* at every sampling, with densities ranging from 4,100 to 28,700 per m^2 (Figure 3). From July through September, station 1.8 M had highest densities on all but one occasion, with a range of 18,500 to 49,700 per m^2. This shift in the station of highest abundance may have resulted from differential mortality sources, such as predation, between the two sites. Predation may have been largely responsible for reduced densities of *C. salmonis* at the lower elevation stations (.6 M and .4 M). Other factors such as food supply or disease may also have contributed to patterns of abundance.

Population densities generally exhibited a gradual decrease during the early portion of spring, 1980 (Figure 3). In early and mid-May, amphipod densities at both 1.8 meter stations began to increase dramatically due to the appearance of large numbers of juveniles, reaching levels of 13,400 per m^2 and 28,700 per m^2 at stations 1.8 M and 1.8 MC, respectively, by the end of May. During July, the population at both stations peaked at over 40,000 per m^2, before leveling off in August and September.

The population at station .6 M began to increase slightly towards the latter half of May, and in July was still at a relatively low level (6600 per m^2). Density did not peak until mid-August. The peak density (18,300 per m^2) was less than half the magnitude of maximum densities seen at the 1.8 meter stations.

Age Structure

The population of *C. salmonis* at all stations contained few young ($\leq$ 2.0 mm) during the early spring (Figure 4). The population was comprised largely of individuals which survived the winter. The increase in reproductive activity during late April and early May resulted in the appearance of large numbers of young

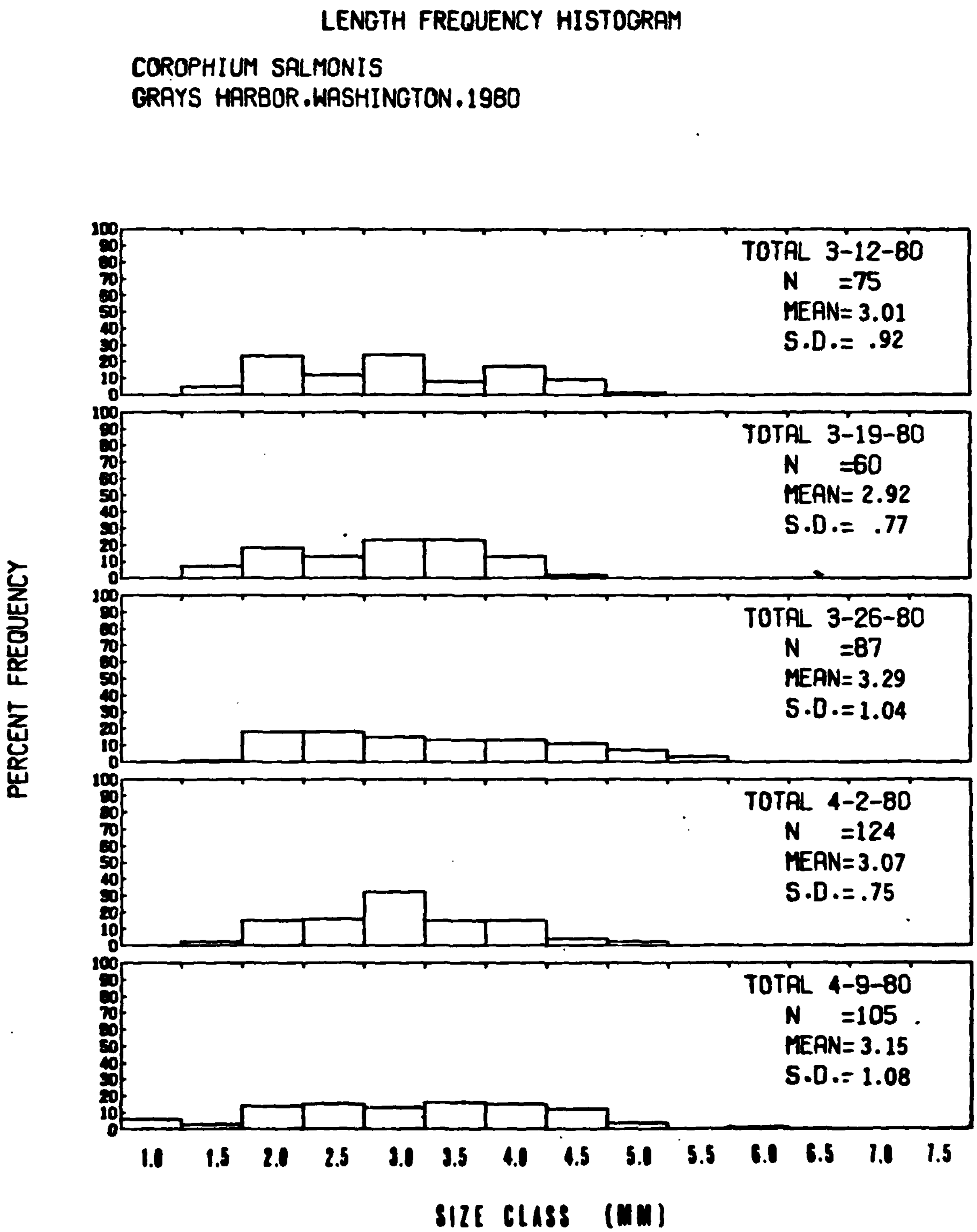

Figure 4: Length-frequency histograms for C. salmonis from all stations between March 12 and April 9, 1980, Grays Harbor, Washington.

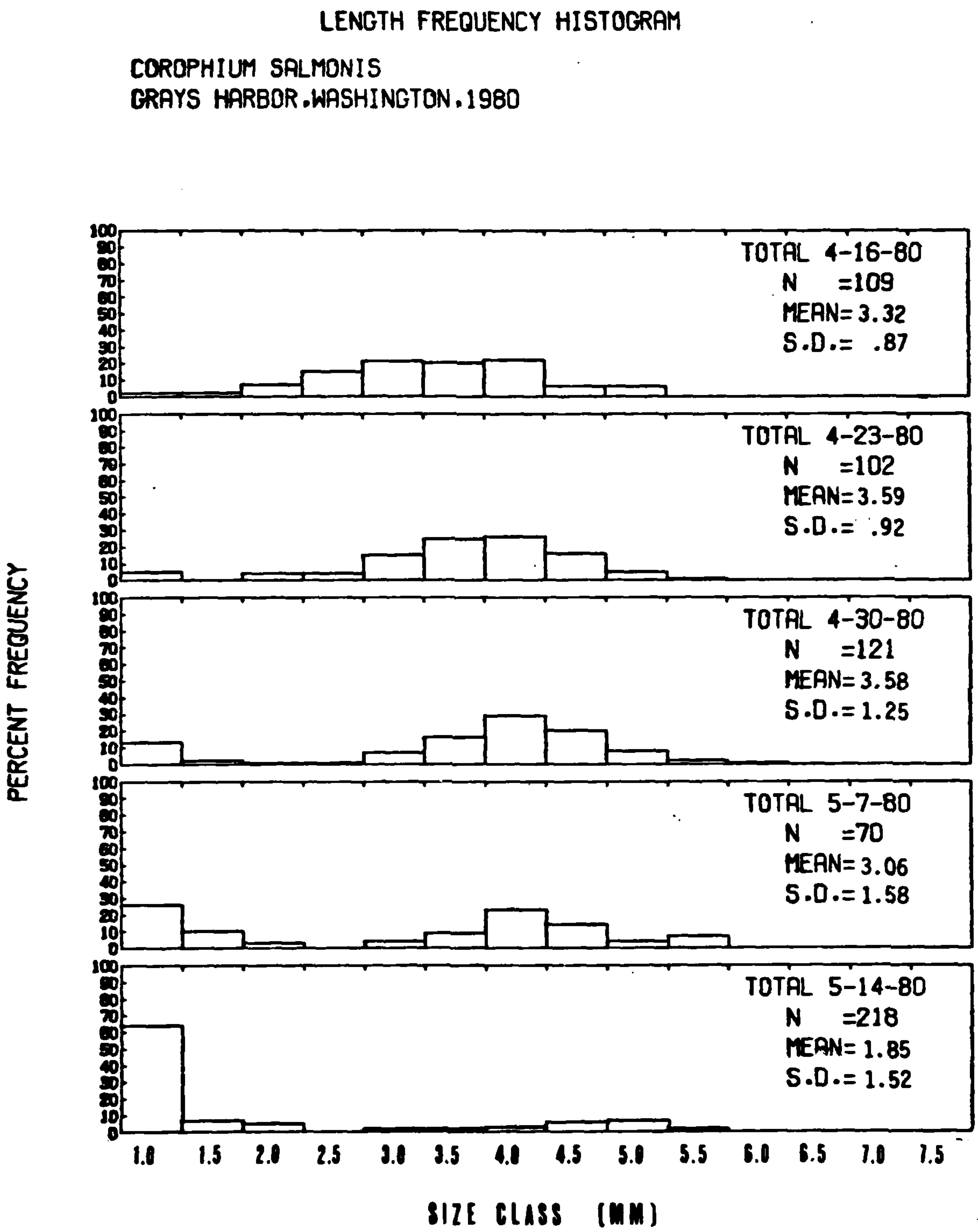

Figure 5: Length-frequency histograms for *C. salmonis* at all stations between April 16 and May 14, 1980, Grays Harbor, Washington.

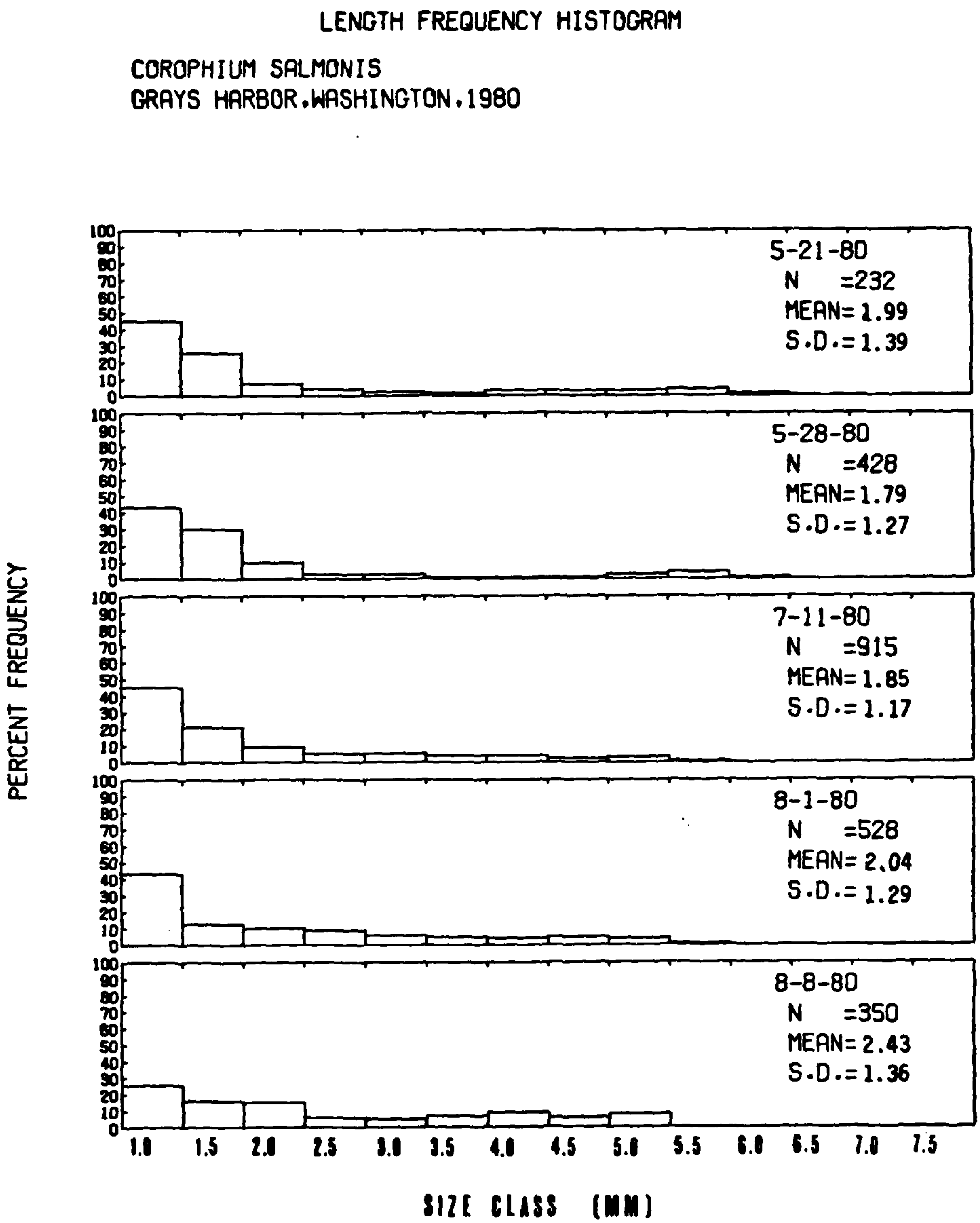

Figure 6: Length-frequency histograms for C. salmonis at all stations between May 21 and August 8, 1980, Grays Harbor, Washington.

LENGTH FREQUENCY HISTOGRAM

COROPHIUM SALMONIS
GRAYS HARBOR.WASHINGTON.1980

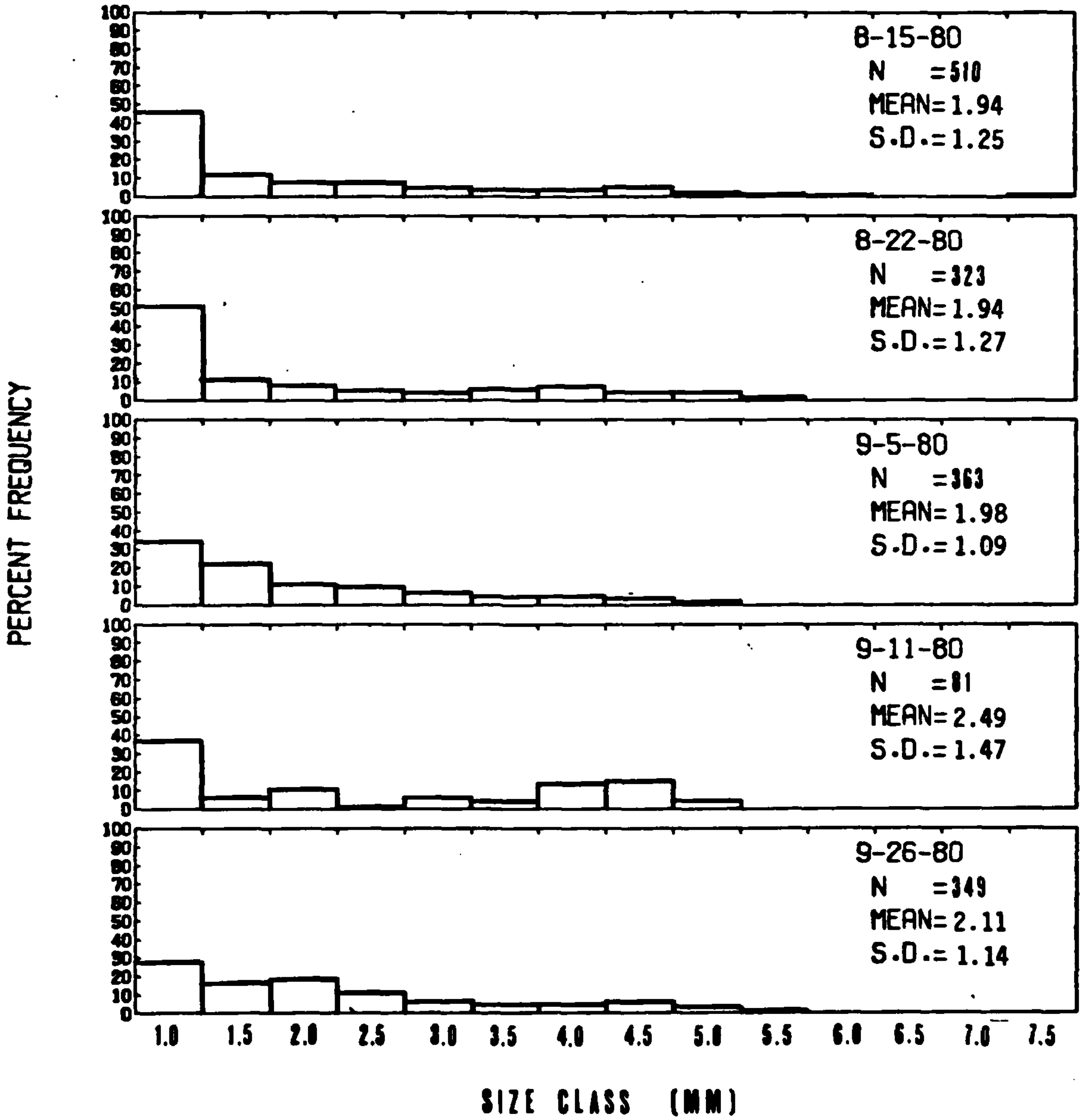

Figure 7: Length-frequency histograms for C. salmonis at all stations between August 15 and September 26,1980, Grays Harbor, Washington.

in the population during May, skewing the population structure towards smaller individuals. This change was reflected in the shape of length-frequency histograms (Figures 4-7).

Reproduction

Females were assumed to have reached sexual maturity when their oostegites were fully developed and bearing setae. During the spring of 1980, 48 percent of the females had fully developed oostegites with gravid. Thus, the majority of females became sexually mature by the time they females were gravid (Table 3). When females reached the 4.5 mm size class, 81 percent had fully developed oostegites with setae and 43 percent were gravid. Thus, the majority of females became sexually mature by the time they reached 4.5 mm in length, although some females were seen bearing eggs when as small as 3.0 mm in length.

Brooding of eggs in female C. salmonis began in late March 1980. The percentage of females which brooded eggs was small at that time, and remained so until the last half of April, when there occurred a large increase in the number of gravid females (Figure 8). Brooding continued at least through the end of September when sampling was discontinued.

The mean number of eggs per gravid female was 11.4 during spring (N = 111), but this is considered a low estimate. During the processes of preservation and subsequent sieving of samples, eggs were surely lost from many brood pouches. Loose eggs were occasionally found during the sorting of C. salmonis from the sieved residue. The number of eggs per brood varied between 1 and 50. Thus, the number of eggs per brood is felt to be considerably higher than indicated. Davis (1978) reported 15.3 eggs per brood for the Columbia River Estuary, but it is likely that even this figure

Table 3: Size at which female C. salmonis reach sexual maturity in Grays Harbor, Washington, spring of 1980.

	Size (mm)							
	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5
Percent of females having fully developed oostegites with setae	3	7	48	81	95	96	100	100
Percent of females bearing eggs in brood pouch	1	4	22	43	43	64	80	33

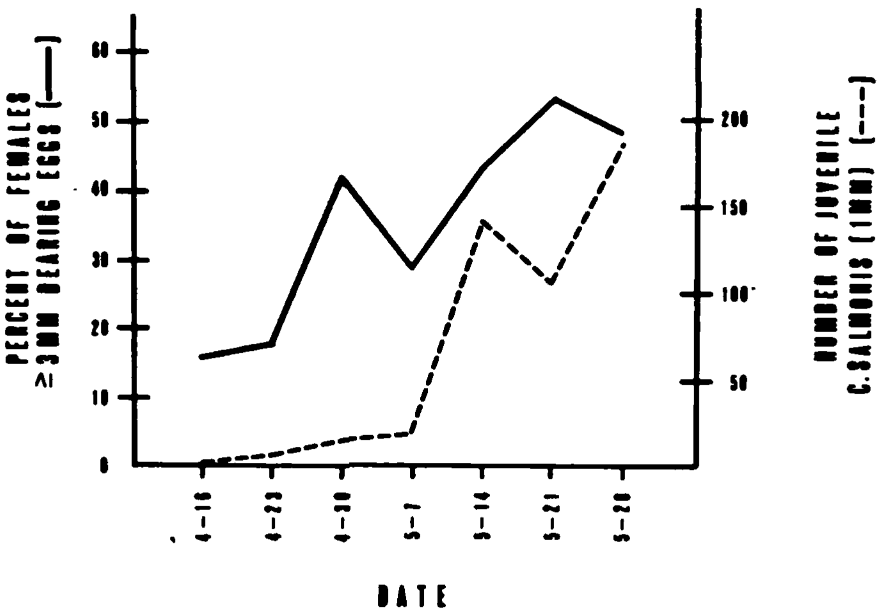

Figure 8: Percent of female C. salmonis in gravid condition, and number of juvenile C. salmonis, Grays Harbor, Washington, 1980.

is low for Grays Harbor. Collection of a small number of live females suggested that the number of eggs per brood is higher, with perhaps 35 eggs per brood upon fertilization and 15-17 eggs at the time of egg maturation.

The number of eggs per brood appeared to vary during the course of the breeding season. A general trend of increasing number of eggs per brood was apparent as spring progressed (Table 4).

The duration of embryonic development was estimated by plotting the percentage of gravid females in the spring alongside the number of juveniles in the 1.0 mm size class, the size class which contains newly hatched young (Figure 8). It appears from this graph that an increase in number of juveniles followed two weeks after the appearance of a sudden increase in the percentage of gravid females, suggesting a gestation period of two to three weeks from egg deposition to hatching.

Male-Female Ratios

It has been reported that sexually mature males of *Corophium* tend to wander over the tideflats during the breeding season in search of females, exposing themselves to higher than normal rates of predation (P. Reimers, Oregon Fish and Wildlife Commission, pers. comm., 1981). It appears as if this phenomenon may be occurring in Grays Harbor also, as male-female ratios tend to be lower for individuals greater than or equal to 4.0 mm in length (the size at which approximately 50 percent of females reach sexual maturity, and at which size it is assumed males will begin to wander over the tideflats in substantial numbers) than for individuals less than 4.0 mm (Table 5). This effect is more pronounced in the late spring and summer than in early spring. It is possible that predation pressure increased during late spring and summer, contributing to changing male-female ratios at this time.

Male-female ratios for *C. salmonis* at station .6 M were higher for

Table 4: Mean number of eggs per brood for *C. salmonis* during spring, Grays Harbor, Washington, 1980.

	Date									
	3-26	4-2	4-9	4-16	4-23	4-30	5-7	5-14	5-21	5-28
Mean number of eggs per brood	5.0	3.0	5.0	6.0	9.5	8.4	13.0	16.5	10.5	14.2

Table 5: Male-female ratios for Corophium salmonis at Sites M and MC, Grays Harbor, Washington, 1980.

Male-Female Ratios

Station	Date	<4.0 mm[1]	≥4.0 mm[2]
1.5 M	3-12 to 3-26	.65	.77
1.5 M	4-2 to 4-30	.81	.80
1.8 M	5-7 to 5-28	1.23	.54
1.8 M	7-11 to 9-26	.93	.48
1.8 MC	4-2 to 5-7	.72	.65
1.8 MC	5-14 to 8-22	.77	.39
1.8 MC	9-5 to 9-26	1.12	.20
.6 M	4-2 to 4-30	.59	.37
.6 M	5-7 to 5-28	1.40	.38
.6 M	7-11 to 8-15	1.10	.28
.6 M	9-5 to 9-26	1.45	.12

[1] Excludes young less than 2.0 mm, which could not be reliably sexed as their sexually dimorphic traits were not consistently developed.

[2] 4.0 mm is the size at which approximately 50 percent of females reach sexual maturity, and at which it is assumed males will begin to wander over the tideflats in substantial numbers.

individuals less than 4.0 mm in length and considerably lower for individuals 4.0 mm or larger in comparison to ratios at higher elevations. This substantial reduction in the proportion of males may reflect a greater intensity of predation at this lower intertidal station, which was more accessible to fish and other epibenthic predators because it was covered by water for longer periods of time. In addition, there was a trend to higher male-female ratios among juveniles later in summer when male-female ratios for mature individuals decreased. Populations of C. salmonis at higher elevation stations also showed, although less dramatically, a general trend to higher male-female ratios in juveniles as the male-female ratio in larger individuals decreased through the summer.

LENGTH-WEIGHT REGRESSION ANALYSIS

Separate linear regression analyses of ln weight versus ln length were performed for males and females. The resulting equations obtained (see Table 6) were:

Males: $W = .00424 \cdot L^{3.01825}$

Females: $W = .00595 \cdot L^{2.56817}$

Table 6: Results of length-weight regression analysis for C. salmonis, Grays Harbor, Washington, 1980.

Sex	Coefficient	Estimated Value	Standard Error	R^2	n
Male	b	.00424	.155	.95	31
	m	3.01825	.122		
Female	b	.00595	.128	.95	37
	m	2.56817	.100		

The statistical significance of the differences between coefficients for the two equations were tested according to Kleinbaum and Kupper (1978), as follows:

$$\text{For } m; \quad Z = \frac{\hat{m}_{males} - \hat{m}_{females}}{\sqrt{s^2_{\hat{m}_{males}} + s^2_{\hat{m}_{females}}}}$$

$$\text{For } b; \quad Z = \frac{\hat{b}_{males} - \hat{b}_{females}}{\sqrt{s^2_{\hat{b}_{males}} + s^2_{\hat{b}_{females}}}}$$

The values of m (the intercepts) for the two equations were not significantly different at the five percent level ($Z = 1.676$). The value of b (slope of the line) for females was significantly greater than that for males ($P < .01$, $Z = 2.575$); as a result, calculations of biomass for males and females were based on the separate regression equations.

GROWTH RATE AND PRODUCTION

Estimates of growth rate were primarily based upon the results of the length-frequency histograms resulting from sampling of natural populations of *C. salmonis* during spring of 1980. On April 2, a distinct group of individuals with a mean length of 3.0 mm was evident from the length-frequency histogram. The growth of this group could be followed until May 28, when mean size was 5.4 mm (Table 7). Biomass was computed separately for males and females using the length-weight regression equations derived previously.

Results of the growth of cohorts isolated inside the cages were used to provide information on growth rates of younger individuals (Table 8). Growth could only be validly determined between August 7 and August 15, during

Table 7: Growth of natural populations of *Corophium salmonis* at Sites M and MC during spring, 1980, Grays Harbor, Washington.

Date	Length(mm)	Male Biomass (mg)	Female Biomass (mg)
3-26	2.47	.0647	.0605
4-2	3.00	.1168	.1000
4-9	3.23	.1461	.1209
4-16	3.28	.1528	.1256
4-23	3.71	.2223	.1729
4-30	4.04	.2859	.2141
5-7	4.22	.3274	.2403
5-14	4.44	.3808	.2733
5-21	4.92	.5221	.3569
5-28	5.40	.6874	.4517

Table 8: Growth of caged population of *Corophium salmonis* at Site M, Grays Harbor, Washington, August 1980.

Date	Length(mm)	Male Biomass (mg)	Female Biomass (mg)
8-7	1.41	.0120	.0144
8-15	2.00	.0344	.0353

which time the Corophium present inside the cages grew from 1.4 mm to 2.0 mm in length. After August 15, the number of C. salmonis inside the cages was extremely small. Adult females were present inside some of the cages after one month, although their numbers were so few that it was impossible to determine whether these females grew to adult size in the cages or were anomolous occurrences due to "invasion" of the cages.

A curve of growth rate versus size was constructed for both males and females (Figure 9), from which size-specific growth rates could be estimated. The curves were fitted by eye. Males had slightly higher growth rates in terms of biomass than females. Growth rates of juveniles 1.5 mm in length were extremely high (56 and 48 yr^{-1} for males and females, respectively). (Although the units for growth rate, yr^{-1}, appear awkward, the growth rate is actually expressed as a rate of change of biomass per unit time divided by biomass; the result is that biomass units cancel out, leaving the units of "per unit of time", or yr^{-1} in this case. For further explanation, see Crisp, 1971.) Growth rates dropped as size increased, reaching values of 8.3-10 yr^{-1} at 4.0 mm, before increasing slightly to form a second peak in the growth rate curve at 5.0 mm. The occurrence of the second peak in the growth rate curve is somewhat surprising. Birklund (1977) found no such comparable peak for Corophium insidiosum and Corophium volutator, although the remainder of his growth rate curves were extremely similar to that for Corophium salmonis.

Tables 9-11 show the details of calculations for production between April 1 and September 30 at stations 1.8 MC, 1.8 M and .6 M respectively. The results are summarized in Table 12. Total C. salmonis production for each station between April 1 and September 30 varied from 3.6 grams per m^2 at station .6 M to 10.7 grams per m^2 at station 1.8 M, and was considerably greater at the higher elevation stations (1.8 M and 1.8 MC) than at the

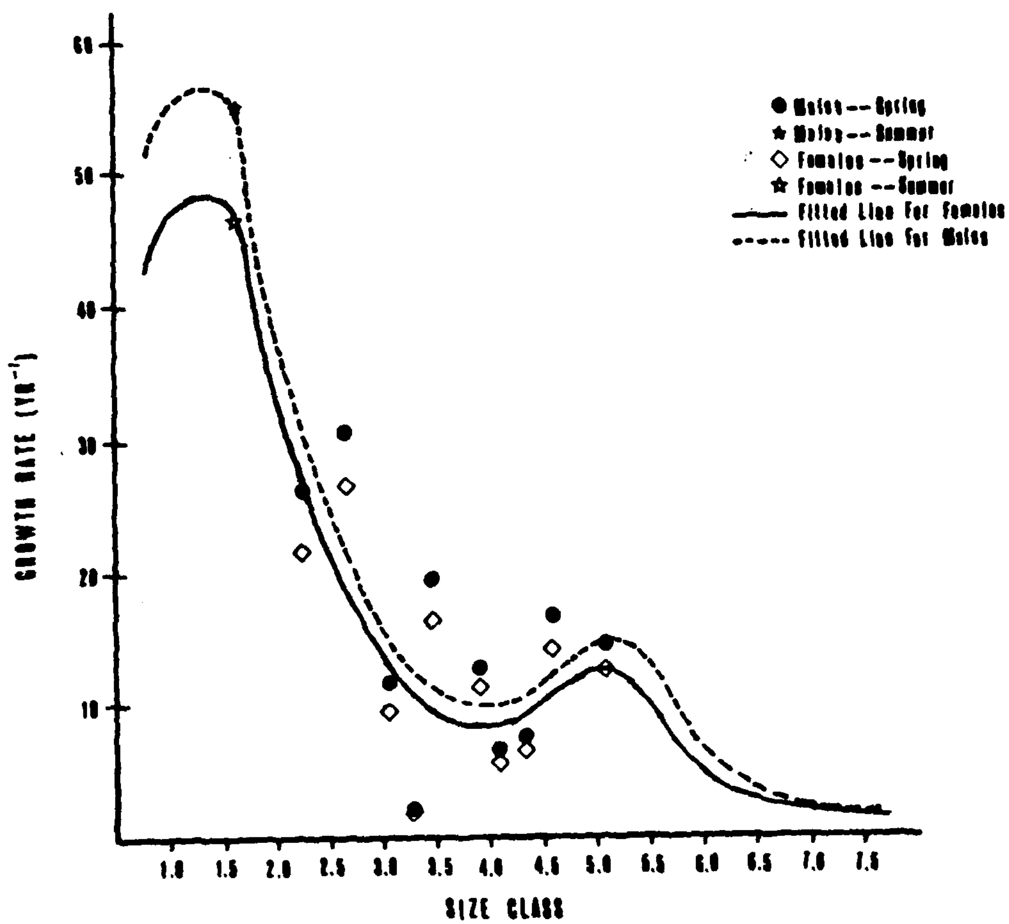

Figure 9: Size-specific growth rates for <u>Corophium salmonis</u>, Grays Harbor, Washington, 1980.

Table 9: Production at the 1.8 m station at Site MC between April 1 and September 30, Grays Harbor, Washington, 1980

					4-1-80 to 5-10-80				Δt=.110 yr.[3]		5-11-80 to 8-29-80				Δt=.304 yr.		8-30-80 to 9-30-80				Δt=.088 yr.	
Size Class	Mean Dry Wt. (mg) M[1]	Mean Dry Wt. (mg) F[2]	Size Specific Growth Rate M	Size Specific Growth Rate F	Mean No. Per m^2 M	Mean No. Per m^2 F	Mean Biomass (Mg Per m^2) M	Mean Biomass (Mg Per m^2) F	Production (Mg Per m^2) M	Production (Mg Per m^2) F	Mean No. Per m^2 M	Mean No. Per m^2 F	Mean Biomass (Mg Per m^2) M	Mean Biomass (Mg Per m^2) F	Production (Mg Per M^2) M	Production (Mg Per M^2) F	Mean No. Per m^2 M	Mean No. Per m^2 F	Mean Biomass (Mg Per M^2) M	Mean Biomass (Mg Per M^2) F	Production (Mg Per M^2) M	Production (Mg Per M^2) F
1.0	.0042	.0060	54.2	46.1	231	323	.97	1.98	5.79	10.04	3,334	5,000	14.00	29.75	230.68	374.89	1,884	2,397	7.91	14.62	37.73	57.85
1.5	.0144	.0169	56.0	48.0	90	108	1.30	1.83	6.01	9.66	1,686	3,184	24.28	53.81	413.34	785.20	335	721	5.11	12.18	25.18	51.45
2.0	.0344	.0353	38.3	34.2	253	216	8.70	7.62	36.65	28.66	907	1,069	31.20	37.74	363.27	392.38	295	253	10.15	8.93	34.21	26.88
2.5	.0674	.0626	25.1	21.6	289	289	19.48	18.09	53.79	42.98	528	717	35.59	44.88	271.57	294.70	391	198	26.35	12.39	58.20	23.55
3.0	.1168	.1000	15.7	14.0	487	649	56.88	64.90	98.23	99.95	528	568	61.67	56.80	294.34	241.74	343	337	40.06	33.70	55.35	41.52
3.5	.1860	.1485	11.3	9.4	379	794	70.49	117.91	87.62	121.91	243	528	45.20	78.41	155.27	224.06	114	235	21.20	34.90	21.08	28.87
4.0	.2783	.2093	10.0	8.3	541	884	150.56	185.02	165.62	168.93	379	487	105.48	101.93	320.66	257.19	265	523	73.75	109.46	64.9	79.95
4.5	.3971	.2832	11.5	10.0	271	577	107.61	163.41	136.12	179.75	135	501	53.61	141.88	187.42	431.32	108	740	42.89	209.57	43.40	184.42
5.0	.5458	.3712	14.6	12.5	198	126	108.07	46.77	173.56	64.30	68	406	37.11	150.71	164.71	572.70		523		194.14		213.55
5.5	.7277	.4741	12.7	9.8	54	72	39.30	34.14	55.77	36.80	81	203	58.94	96.24	231.14	286.72		72		34.14		29.44
6.0	.9463	.5928	6.3	5.7	18	18	17.03	10.67	11.80	6.69	14	95	13.25	56.32	25.38	97.59						
6.5	1.2049	.7281	3.5	2.8								41		29.85		25.41						
7.0	1.5069	.8808	2.2	1.9																		
7.5	1.8558	1.0515	1.7	1.6																		
Total for each sex =							529.09	848.26	832.96	769.67			480.33	878.32	2667.78	3983.90			227.42	663.67	340.05	737.48
Overall total							B = 1440.45		P = 1602.63				B = 1358.65		P = 6641.68				B = 891.09		P = 1077.53	

Production (weight per m^2) = 9321.84 mg per m^2 = 9.32 g per m^2

Mean Biomass (weight per m^2) = 1294.61 mg per m^2 = 1.30 g per m^2

Production/Mean Biomass = 7.2

[1]Males

[2]Females

[3]Time interval in years

Table 10: Production at the 1.8 m station at Site M between April 1 and September 30, Grays Harbor, Washington, 1980.

					4-1-80 to 4-30-80[4]				Δt[3]=.082 yr.		5-1-80 to 5-31-80				Δt=.085 yr.		6-1-80 to 9-30-80				Δt=.334 yr.	
Size Class	Mean Dry Wt. M[1]	Mean Dry Wt. F[2]	Size Specific Growth Rate M	Size Specific Growth Rate F	Mean No. Per m^2 M	Mean No. Per m^2 F	Mean Biomass (Mg Per m^2) M	Mean Biomass (Mg Per m^2) F	Production (Mg Per m^2) M	Production (Mg Per m^2) F	Mean No. Per m^2 M	Mean No. Per m^2 F	Mean Biomass (Mg Per m^2) M	Mean Biomass (Mg Per m^2) F	Production (Mg Per m^2) M	Production (Mg Per m^2) F	Mean No. Per m^2 M	Mean No. Per m^2 F	Mean Biomass (Mg Per m^2) M	Mean Biomass (Mg Per m^2) F	Production (Mg for m^2) M	Production (Mg for m^2) F
1.0	.0042	.0060	54.2	46.1	44	86	.18	.51	.80	1.93	933	2,178	3.92	12.96	18.06	50.78	4,800	6,108	20.16	36.34	364.95	559.54
1.5	.0144	.0169	56.0	48.0	0	65	0	1.10	0	4.33	287	904	4.13	15.28	19.66	62.34	1,158	2,243	16.68	37.91	311.98	607.77
2.0	.0344	.0353	38.3	34.2	130	195	4.47	6.88	14.04	19.29	135	108	4.64	3.81	15.11	11.08	1,319	1,876	45.37	66.22	580.38	756.42
2.5	.0674	.0626	25.1	21.6	281	195	18.94	12.21	38.98	21.63	81	135	5.46	8.45	11.65	15.51	830	763	55.94	47.76	468.97	344.56
3.0	.1168	.1000	15.7	14.0	303	303	35.39	30.30	45.56	34.78	81	54	9.46	5.40	12.62	6.43	660	621	77.09	62.10	404.24	290.38
3.5	.1860	.1485	11.3	9.4	216	455	40.18	67.57	37.23	52.08	135	54	25.11	8.02	24.12	6.41	703	531	130.76	78.86	493.51	247.59
4.0	.2783	.2093	10.0	8.3	281	389	78.20	81.42	64.12	55.41	162	216	45.08	45.21	38.32	31.90	590	688	164.20	144.00	548.43	399.20
4.5	.3971	.2832	11.5	10.0	86	108	34.15	30.59	32.20	25.08	216	162	85.77	45.88	83.84	39.00	216	866	85.77	245.25	329.44	819.14
5.0	.5458	.3712	14.6	12.5	65	43	35.48	15.96	42.48	16.36	135	325	73.68	120.64	91.44	128.18	301	533	164.29	197.85	801.14	826.02
5.5	.7277	.4741	12.9	9.8							27	216	19.65	102.41	21.55	85.31	15	119	10.92	56.42	45.59	184.67
6.0	.4963	.5928	6.3	5.7								81		38.40		18.60		31		14.70		27.99
6.5	1.2049	.7281	3.5	2.8														64		46.60		
7.0	1.5069	.8808	2.2	1.9																		
7.5	1.8558	1.0515	1.7	1.6														15		15.77		8.43
Total biomass & production @ sex =							246.99	246.54	275.41	230.89			276.90	406.46	336.37	455.54			771.18	1049.78	4348.63	5071.71
Overall total =							B = 493.53		P = 506.30				B = 683.36		P = 791.91				B = 1820.96		P = 9420.34	

Production (weight per m^2) = 10,718.55 mg per m^2 = 10.72 g per m^2
Mean biomass (weight per m^2) = 1,410.69 mg per m^2 = 1.41 g per m^2
Production/Mean Biomass = 7.6

[1]Males

[2]Females

[3]Time interval in years

[4]Density, biomass and production computed using data from 1.5 m station.

Table 11: Production at the .6 m station at Site M between April 1 and September 30, Grays Harbor, Washington, 1980.

Stations .6 M and .4 M

Size Class	Mean Dry Wt. M[1]	Mean Dry Wt. F[2]	Size Specific Growth Rate M	Size Specific Growth Rate F	4-1-80[4] to 4-30-80 Δt[3]=.082 yr. Mean No. Per m^2 M	Mean No. Per m^2 F	Mean Biomass Per m^2 M	Mean Biomass Per m^2 F	Production M	Production F
1.0	.0042	.0060	54.2	46.1	13	23	.06	.14	.27	.53
1.5	.0144	.0169	56.0	48.0	6	12	.09	.20	.41	.79
2.0	.0344	.0353	38.3	34.2	24	69	.83	2.44	2.61	6.84
2.5	.0674	.0626	25.1	21.6	39	18	2.63	1.13	5.41	2.00
3.0	.1168	.1000	15.7	14.0	72	126	8.41	12.60	10.83	14.46
3.5	.1860	.1485	11.3	9.4	75	147	13.95	21.83	12.93	16.83
4.0	.2783	.2093	10.0	8.3	111	222	30.89	46.46	25.33	31.62
4.5	.3971	.2832	11.5	10.0	18	168	7.15	47.58	6.74	39.02
5.0	.5458	.3712	14.6	12.5	36	54	19.65	20.04	23.52	20.54
5.5	.7277	.4741	12.9	9.8						
6.0	.9463	.5928	6.3	5.7						
6.5	1.2049	.7281	3.5	2.8						
7.0	1.5069	.8808	2.2	1.9						
7.5	1.8558	1.0515	1.7	1.6						
Total for each sex =							83.66	152.42	88.05	132.63
Overall total =							B = 236.08		P= 220.68	

Size Class	*5-1-80 to 6-15-80 Δt=.123 yr. Mean No. Per m^2 M	Mean No. Per m^2 F	Mean Biomass Per m^2 M	Mean Biomass Per m^2 F	Production M	Production F
1.0	406	406	1.72	2.42	11.47	13.72
1.5	126	180	1.81	3.04	12.47	17.95
2.0	90	72	3.10	2.54	14.60	10.68
2.5	18	0	1.21	0	3.74	0
3.0	0	18	0	1.80	0	3.10
3.5	18	0	3.55	0	4.93	0
4.0	36	18	10.02	3.77	12.32	3.85
4.5	0	72	0	20.39	0	25.08
5.0	36	90	19.65	33.41	35.29	51.37
5.5		36		17.07		20.58
6.0						
6.5						
7.0						
7.5						
Total for each sex =			41.06	84.44	94.82	146.33
Overall total =			B = 125.50		P= 241.15	

Size Class	6-16-80 to 8-25-80 Δt=.195 yr. Mean No. Per m^2 M	Mean No. Per m^2 F	Mean Biomass M	Mean Biomass F	Production M	Production F
1.0	3,281	3,700	13.91	22.02	147.01	197.95
1.5	823	1,098	11.85	18.56	129.40	173.72
2.0	595	541	20.47	19.10	152.88	127.38
2.5	460	379	31.00	23.73	151.73	99.95
3.0	135	135	15.77	13.50	48.28	36.86
3.5	243	243	45.20	36.09	99.60	66.15
4.0	108	298	30.06	62.37	58.62	100.95
4.5	54	325	21.44	92.04	48.08	179.48
5.0	108	271	58.95	100.60	167.83	245.21
5.5		54		25.60		48.92
6.0		27		9.49		10.55
6.5						
7.0						
7.5						
Total for each sex =			248.65	423.1	1003.43	1287.12
Overall total =			B = 671.75		P = 229(.55	

Size Class	8-26-80 to 9-30-80 Δt=.099 yr. Mean No. Per m^2 M	Mean No. Per m^2 F	Mean Biomass M	Mean Biomass F	Production M	Production F
1.0	947	947	4.02	5.63	21.57	25.69
1.5	379	974	5.46	16.46	30.27	78.22
2.0	866	704	29.79	24.85	112.95	84.14
2.5	868	325	58.37	20.35	145.04	43.52
3.0	650	270	75.92	27.00	118.00	37.42
3.5	54	379	10.04	56.28	11.23	52.37
4.0	54	271	15.03	56.72	14.88	46.61
4.5	0	162	0	45.88	0	45.42
5.0						
5.5						
6.0						
6.5						
7.0						
7.5						
Total for each sex =			198.63	253.17	453.94	413.39
Overall total =			B =451.80		P= 867.33	

Production (weight per m^2) = 3619.71 mg per m^2 = 3.62 g per m^2
Mean biomass (weight per m^2) = 421.87 mg per m^2 = .42 g per m^2
Production/Mean biomass = 8.6

[1]Males
[2]Females
[3]Time interval in years
[4]Density biomass and production computed using data from both .6 M and .4 M

Table 12: Production, mean biomass, and production/mean biomass values for *C. salmonis* at Sites M and MC between April 1 and September 30, Grays Harbor, Washington, 1980.

Station	Total Production (grams m^{-2}) between April 1 and September 30	Mean Biomass (grams m^{-2}) between April 1 and September 30	Production/ Biomass
.6 M	3.62	.42	8.6
1.8 M	10.72	1.14	7.6
1.8 MC	9.32	1.30	7.2

lower elevation station (.6 M). This reflected the higher population densities at the 1.8 meter stations. *C. salmonis* production was slightly higher at station 1.8 M (10.7 g per m^2) than station 1.8 MC (9.3 g per m^2). *C. salmonis* production was probably also higher at Site M than Site MC at the .6 meter stations, due to the small number of *C. salmonis* at .6 MC. Thus Site M had higher overall *C. salmonis* production than Site MC.

The amount of *C. salmonis* production during spring was less than in summer, especially at stations .6 M (6 $mg \cdot m^{-2} \cdot day^{-1}$) and 1.8 M (21 $mg \cdot m^{-2} \cdot day^{-1}$). While production at 1.8 MC was also low during early spring, the population density at station 1.8 MC began to increase dramatically during the latter part of May, resulting in a high rate of daily production during late Spring (40 $mg \cdot m^{-2} \cdot day^{-1}$). Station 1.8 M showed a lesser increase in *C. salmonis* production in late May. Station .6 M did not begin to show an increase in its production until later in the summer. Daily production was high at all stations (relative to the total production for each station) during August and September (28 mg-, 77 mg-, and 48 $mg \cdot m^{-2} \cdot day^{-1}$ at stations .6 M, 1.8 M, and 1.8 MC, respectively).

DISCUSSION

POPULATION STRUCTURE

Densities of C. salmonis varied greatly at both Sites M and MC during the sampling period. At Station .6M, for example, the population density varied from a low of 216 per m^2 (May 14, 1980) to 18,308 per m^2 (August 15, 1980). The densities at Sites M and MC were comparable to densities found in Grays Harbor during 1974-75 (Table 13), especially at the 1.8 meter stations. However, the use of a .5 mm sieve and live sieving of samples in the 1974-75 study may have resulted in artificially low population densities by allowing juvenile C. salmonis to escape through the sieve (Albright and Rammer, 1976). Despite this difference in sampling efficiency, consistently higher densities were reported in 1974-75 from the muddy-sand sediments of the mid-harbor flats (station elevations were all between .9 and 1.2 meters), where maximum density was 56,000 per m^2. The high densities observed during March 1975 are of interest, as during March 1980, densities at Sites M and MC were all less than 10,000 per m^2. This may indicate that muddy-sand sediments constitute a preferred habitat for C. salmonis. Other areas which had high peak densities of C. salmonis during the 1974-75 study were situated adjacent to the Weyerhaeuser pulp mill effluent pond on the South Channel (58,000 C. salmonis per m^2), west of Moon Island in Bowerman Basin (33,000 per m^2), and at the mouth of O'Leary Creek (36,000 per m^2). All three of these sites had mud sediments, composed primarily of silt and clay, and were very similar to Sites M and MC. Differences in peak densities between Sites M and MC and these other mud sites may have been due primarily to year-to-year variation in C. salmonis abundance, as it appears abundance varies widely between years (Herrman et al., 1981).

Table 13: Densities of *C. salmonis* in Grays Harbor, Washington. Data for all locations except Sites M and MC taken from Albright and Rammer, 1976.

Location	Date	Elevation	Mean No. per m^2	Max. no. per m^2	Sediment
Mid-harbor flats	3-75	.9-1.2 m	36,700	50,000	Muddy sand
Mid-harbor flats	8-75	.9-1.2 m	32,300	56,000	Muddy sand
W. of Moon Island	10-74, 4-75, 7-75	1.8 m	4,900	6,800	Muddy sand
W. of Moon Island	10-74, 5-75, 7-75	1.8 m	7,700	14,600	Fine sand
W. of Moon Island	10-74, 4-75, 7-75	1.6 m	3,300	7,600	Fine sand
W. of Moon Island	10-74, 4-75, 7-75	2.1 m	3,700	6,200	Fine sand
W. of Moon Island	12-74, 5-75, 7-75	1.6 m	17,000	32,800	Mud
W. of Moon Island	12-74, 5-75, 7-75	2.2 m	3,000	5,900	Fine sand
E. end of Bowerman Basin	11-74, 7-75	~2.1 m	3,300	5,800	Mud
Mouth of O'leary Creek	9-74	~1.8 m	35,900	35,900	Mud
Mouth of Grass Creek	9-74, 10-74, 11-74	~2.2 m	200	300	Muddy sand
South Channel w. of Charlie Creek	11-74	~1.8 m	57,900	57,900	Mud
Site M	3-80 to 9-80	.6 m	6,600	18,300	Mud
		1.8 m	11,400	49,700	Mud
Site MC	3-80 to 9-80	1.8 m	13,300	42,400	Mud

The distribution and abundance of C. salmonis appears to be determined largely by sediment type and beach slope. Muddy-sand or mud substrates present on broad, gently sloping tideflats appear to support the highest population densities. While C. salmonis primarily occurs in lower salinity regimes, natural variations in salinity over the course of the year are great in the inner portions of Grays Harbor. Thus, salinity does not appear to be as important a factor in controlling C. salmonis distribution and abundance in Grays Harbor as sediment type.

Elevation is also an important factor in determining C. salmonis distribution and abundance. Population densities were higher at 1.8 meters than .6 meters on all but one occasion (August 8). The abundances of C. salmonis present at Site M on May 14 and 15, 1980, are listed in Table 14. Sampling on these dates was performed at both the initial, incorrectly located sample stations, as well as the new, properly located sample stations. Also included are additional samples collected at 2.1, .2, and 0 meters above MLLW as part of additional USACE funded studies to determine benthic invertebrate abundance and distribution patterns in relation to the proposed channel widening and deepening project. These latter samples are not directly comparable to the data collected at the .4, .6, 1.5 and 1.8 meter stations as they were live-sieved using a .5 mm sieve. However, they do help illustrate the general trend of decreasing C. salmonis abundance intertidally as elevation decreases from +2.1 meters to MLLW (0 meters).

Biotic factors may also be important in controlling the distribution and abundance of C. salmonis. Predation, in particular, is a likely factor and is probably a major contributing cause to changes in density at different elevations. Three pieces of evidence support the belief that predation affects the abundance and distribution of C. salmonis:

Table 14: Abundance of Corophium salmonis at Site M by elevation, Grays Harbor, Washington, May, 1980.

.3 mm Seive			.5 mm Seive		
Station Elevation	Date	Abundance Per M^2	Station Elevation	Date	Abundance Per M^2
			2.1 m	5-4-80	3636
1.8 m	5-14-80	6169			
1.5 m	5-15-80	1948			
			1.2 m	5-14-80	3030
.6 m	5-14-80	216			
.4 m	5-15-80	1732			
			0 m	5-14-80	0

1) A higher rate of mortality occurred for mature males, which resulted in lower male-female ratios among individuals 4.0 mm or larger. The observed changes in the ratio of males to females with increasing size corresponds to similar observations for other tube-dwelling amphipods. Hastings (1981) found a comparable pattern for *Ampelisca brevicornis*. Males of *A. brevicornis*, like males of *C. salmonis*, are reported to leave their burrows after reaching sexual maturity in search of sexually active females, who remain in their burrows. The males are exposed to much higher than normal predation pressure during these wanderings. Barnard (1960) has reported a scarcity of mature males in collections of sublittoral ampeliscids from Southern California.

2) Results of food habit studies in Grays Harbor showed a variety of predators use *C. salmonis* as a food resource (Smith and Mudd, 1976; Bengston and Brown, 1976; Kalinowski, pers. comm.[1], 1981; Martin, pers. comm.[2], 1981), and

3) Predators which use *C. salmonis* as a food resource were present at Sites M and MC (Kalinowski, pers. comm., 1981).

The high male-female ratios found for juvenile *C. salmonis* when ratios for sexually mature individuals were low may indicate a genetic response to offset a high rate of predation on sexually mature males. Such a response has been discussed for copepods by Battaglia (1964). The response in sex ratio for copepods was related to population density rather than enhanced predation

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on one sex, however. When densities of copepods were low, male-female ratios were high. Presumeably this would be advantageous in ensuring that all females, including the more timid individuals, were fertilized. When copepod densities were high, male-female ratios were low, as one male could fertilize the eggs of several females (Warwick, 1980). This same relationship between sex ratio and population density did not appear to contribute to sex ratios for C. salmonis in Grays Harbor. As the population density increased during late spring and summer, the male-female ratio for immature C. salmonis (whose sex ratio is presumeably less affected by predation than the sex ratio for sexually mature individuals) increased rather than decreased.

GROWTH RATE AND PRODUCTION

The fitted size-specific growth rate curve derived from this study was very similar in most respects to those derived by Birklund (1977) for Corophium insidiosum. An exception was the decrease in the growth rate at 4.0 mm and subsequent rise to a second peak at 5.0 mm (Figure 9). The decrease very likely was caused by the onset of sexual maturity and the channeling of energy into reproduction. The second peak in the growth rate curve was the most anomalous feature of the curve. This may have resulted from a resumption in growth after reproduction, or perhaps it may have reflected a response to environmental conditions particularly conducive to rapid growth.

The estimates of production for C. salmonis obtained in this study (Table 12) were relatively high compared to production estimates of other marine macroinvertebrates with comparable life spans (Table 15). Actual annual production figures are probably even higher, as the values obtained in this study do not cover the time period between October 1 and March 30, although

Table 15: Production and $P/\bar{B}$ values for invertebrates. Values in grams dry weight per m^2, unless otherwise stated.

Species	Taxon	Production	$P/\bar{B}$	Max. Age	Reference
Ampharete acutifrons	Polychaete	.719 g (wet)	4.58	1	Richards & Riley, 1967
Neomysis americana	Mysid	.0362 g	3.66	1	Richards & Riley, 1967
Littorina saxatilis	Gastropod	3.25 g	4.11	1	Burke & Mann, 1974
Ampharete acutifrons	Polychaete	2.32 g	5.5	1	Warwick & Price, 1975
Ampelisca brevicornis	Amphipod	4.26 g (wet)	3.95	1.25	Klein et al., 1975
A. brevicornis	Amphipod	2.43 g (wet)	3.68	1.25	Klein et al., 1975
Pectinaria californienis	Polychaete	2.02 g C	5.3	1.2	Nichols, 1975
Pectinaria californienis	Polychaete	3.471 g C	4.1	1.8	Nichols, 1975
Pectinaria californienis	Polychaete	1.386 g C	5.5	1.9	Nichols, 1975
Hydrobia ulvae	Gastropod	7.23 g	1.78	1	Wolff & deWolf, 1977
Hydrobia ulvae	Gastropod	8.80 g	1.24	1	Wolff & deWolf, 1977
Ampelisca brevicornis	Amphipod	1.31 - 1.68 g	2.49 - 3.21	1	Hastings, 1981
Ampelisca brevicornis	Amphipod		5	1	Sanders, 1956
Ampelisca tenuicornis	Amphipod	.00103 g(AFDW)	3.4	1	Sheader, 1977
Corophium insidiosum	Amphipod	.2 - 8 g	3-5	1	Birklund, 1977
C. volutator	Amphipod	2-4 g	3-4	1	Birklund, 1977
C. insidiosum	Amphipod	3-60 g	12 - 19.5	1	Casablanca, 1975 (in Birklund, 1977)

it is assumed that the amount of production occurring during this period is comparatively small relative to production between April 1 and September 30.

Turnover rates (the ratio of production, P, to mean biomass, $\overline{B}$) were high in comparison to values reported in the literature for other benthic macroinvertebrates (Table 15). As a multivoltine species (producing several broods per year), however, Corophium species should be expected to have higher $P/\overline{B}$ values than the other species in Table 15, most of which are univoltine (producing only one brood per year). Multivoltine species are generally reported to have $P/\overline{B}$ values of 10, while most univoltine and bivoltine species have $P/\overline{B}$ values between 4 and 7 (McIntyre, 1964; Mann, 1967; Waters, 1977).

Of the organisms listed in Table 15, Corophium insidiosum and C. volutator are the most similar to C. salmonis. Birklund (1977), using techniques very similar to those used in this study, found production values in Denmark for these amphipods ranged from .2-8 grams and 2-4 grams per m^2 for C. insidiosum and C. volutator, respectively. $P/\overline{B}$ values were 3-5 for C. insidiosum and 3-4 for C. volutator. However, Birklund's production figures cover only the period between May 6 and September 4, two months less than the period covered in this study. This may explain much of the difference between the generally lower P and $P/\overline{B}$ values obtained by Birkland and those reported in this study. C. salmonis production during September was relatively high in Grays Harbor, as temperatures in the Pacific Northwest generally remain warm during this month. Examination of length-frequency histograms for C. salmonis in Grays Harbor for September showed that the age structure present during the late spring and summer was maintained and juveniles were still actively recruited into the population. Population densities also remained high. Thus, September production contributed heavily to overall production (24 percent at Station .6M). If revised P and $P/\overline{B}$ values are calculated excluding the September data, the new P' and $P/\overline{B}'$ estimates were both lowered

significantly (e.g., at station .6 M, P' = 2.75 g per m^2, P'/$\overline{B}$' = 6.64; at Station 1.8 MC, P' = 8.24 g per m^2, P'/$\overline{B}$' = 5.97). These revised figures are closer to the values reported from other studies listed in Table 15. In addition, Birklund felt his Corophium production estimates were conservative as a result of slightly underestimating mean biomass (Birklund, 1977; p. 201).

Birklund (1977) found significantly higher Corophium production at a station located near a sewer outfall. He hypothesized that organic enrichment may have been responsible for increasing production. If this were true, the presence of organic effluents from domestic and industrial sources in the heavily populated inner portion of Grays Harbor may contribute to the production of C. salmonis, although data presented in this study did not address this possibility. Casabianca (1975, in Birklund, 1977), who also estimated the production of C. insidiosum, reported an annual production of 3-60 g per m^2 and a P/$\overline{B}$ of 12-19.5. These exceedingly high values were obtained from Corse (in the Mediterranean Sea), and can in part be accounted for by high water temperatures.

The production estimates obtained for species of Corophium in this and other studies are high in comparison to those for other invertebrates (Table 15). Thus, it appears that Corophium species are important contributors to secondary production, reaffirming their importance as a key prey species in Grays Harbor and other northwest estuaries.

SOURCES OF ERRORS

Informational shortcomings for this study include a lack of data on migrations by C. salmonis into or out of areas where the sample stations were located. Examination of age structure data for each station indicated no obvious migrations to or from any station. Davis (1978) showed, however,

that juveniles do swim about in the water column. His calculations of current velocities indicated that in a short time span (hours), these juveniles could be displaced distances greater than a kilometer, and thus "migrations" were distinctly possible. However, Davis also concluded that only a small percentage of juveniles were induced to swim.

Data from only a portion of the year was used to derive the size-specific growth curve. This data was then used to estimate production over a six month time interval. It is probable that the growth rate varied over the course of the study. During early spring, the growth rates derived were likely lower than those which occurred during late spring and summer. Growth rates derived from late spring may have been greater than growth rates during summer, due to a lack of intraspecific competition. Hopefully, these two effects may have worked to partially cancel each other.

Unfortunately, the paucity of information obtained from the growth cages precluded comparisons of spring versus summer growth rates. The information obtained for the growth of young juveniles from the cages may have been conservative due to mechanical effects of the cages. Potential effects from the cages are reduced nutrient flow into the cages, increased anoxia, and reduced flushing of waste products from the sediment surfaces inside the cages. Problems with the growth cages which contributed to the inability to obtain growth data for larger individuals included:

1) Poor recruitment into the cages resulting in a small sample size,

2) Scouring under of the cages, which resulted in many of the cages being invaded by adult C. salmonis and their predators (a storm on August 17 rendered most of the cages at station 1.8 M unusable, which was unfortunate as cages at this elevation had better recruitment and survival of C. salmonis than cages at .6 meters prior to the storm); and

3) Poor survival inside the cages, due in part to the presence of the omnivorous amphipod Eogammarus confervicolus (a predator of C. salmonis).

The use of population growth rates rather than individual growth rates was another source of error in this study. This would tend to conservatively bias the resulting estimate of growth rate (Crisp, 1971; Birklund, 1977).

A universal hazard of such a study is the effect unusual environmental conditions can have on the results obtained. Without gathering data over at least two years, it is impossible to determine the probability of the estimated production being characteristic of "normal" conditions. An unusual occurrence during this study was the eruption of Mt. St. Helens on May 18, 1980, and a subsequent ashfall on Grays Harbor. What impact this may have had on the growth of C. salmonis, if any, cannot be concluded from this study.

POTENTIAL IMPACTS FROM WIDENING AND DEEPENING PROJECT

The preferred habitat of Corophium salmonis is such that this species should be minimally affected by dredging for the proposed widening and deepening project. Broad tideflat areas which C. salmonis inhabits, especially in the mid- and upper-intertidal regions, should not be disturbed except through secondary impacts such as turbidity. However, C. salmonis is subjected to natural turbidity levels as high as those expected to result from dredging (Smith et al., 1976) without apparent impact to the population.

C. salmonis was present in low abundances along the side of the main navigation channel between Cow Point and the top of the Crossover Channel (Albright and Bouthillette, 1981). However, the temporary loss of these

individuals during dredging would not represent the loss of a major resource.

Potentially, the most critical impact to the _C. salmonis_ resource in Grays Harbor is through the disposal of dredged materials. A project has been proposed at Site M which would use dredged materials to raise 16 hectares of intertidal land to an elevation where salt marsh plants would grow. The immediate impact of such a project would be the loss of a large amount of invertebrate biomass. If the mean of the biomass of _C. salmonis_ present at stations .6 M and 1.8 M (.78 g per m^2) were used to represent the mean biomass of _C. salmonis_ for the entire area to be disposed upon, the immediate loss of _C. salmonis_ biomass would be: 16 ha x 10,000 m^2/ha x .78 g per m^2 = 125 kg.

The proposal for disposal calls for the construction of a dike to retain the disposed sediments until they become consolidated. Thus, the dike would probably be retained for at least one year. If _C. salmonis_ were unable to recolonize the disposal area before removal of the dike. and grading of the deposited dredged materials, the total production lost could be estimated using the mean _C. salmonis_ production for stations 1.8 M and .6 M (7.17 g per m^2 for the time interval April 1 to September 30) as follows: 16 ha x 10,000 m^2/ha x 7.17 g per m^2 = 1,147 kg per year. (Actually, this represents only the production lost between April 1 and September 30, which is assumed to be the bulk of production.)

When the disposed sediments were consolidated and sloped, _C. salmonis_ would begin recolonization of portions of the "new" tideflat. However, qualitative observations indicated that _C. salmonis_ is not as abundant among the marsh plants as in the tideflats below. The reason for this could be too high an elevation or competition for space with the marsh plants. With a steeper slope to the exposed tideflats, the surface area with an elevation suitable for recolonization by _C. salmonis_ would be reduced. Thus, there

would occur a net loss of C. salmonis habitat.

The loss of C. salmonis on either the short or long-term would represent a significant loss of a food resource to its predators. Among the predators impacted will be shorebirds, some waterfowl, a variety of fish, and several invertebrate predators such as Crangonid shrimp (Figure 10).

A possible mitigating factor to any loss of the invertebrate food resource would be an increase in primary production which would result if the marsh establishment project were successful. The increased production might enhance secondary production in adjacent areas, and thus partially or fully compensate for the loss of food resources at the marsh establishment site. However, enhanced production may involve a different invertebrate assemblage than that initially impacted at Site M. Thus, any predatory species specifically dependent upon species at Site M such as C. salmonis might be permanently affected by alterations in food resources caused by this project. However, based upon the benthic species present at Site M (Albright and Bouthillette, 1981), this is not very probable.

The possible use of Bowerman Basin as a future dredged material disposal area would represent a long-term (probably permanent) loss of intertidal area. Samples collected from the perimeter of Bowerman Basin on the south and east sides in 1974-75 (Albright and Rammer, 1976) indicate the occurrence of substantial populations of C. salmonis. The quantity of production lost per year from a 100 or 200 hectare disposal site would be very large, especially considering the importance of the Bowerman Basin region to shorebirds (Jack Smith, pers. comm.[1], 1980).

[1] Washington Game Dept., 905 E. Heron, Aberdeen, WA 98520.

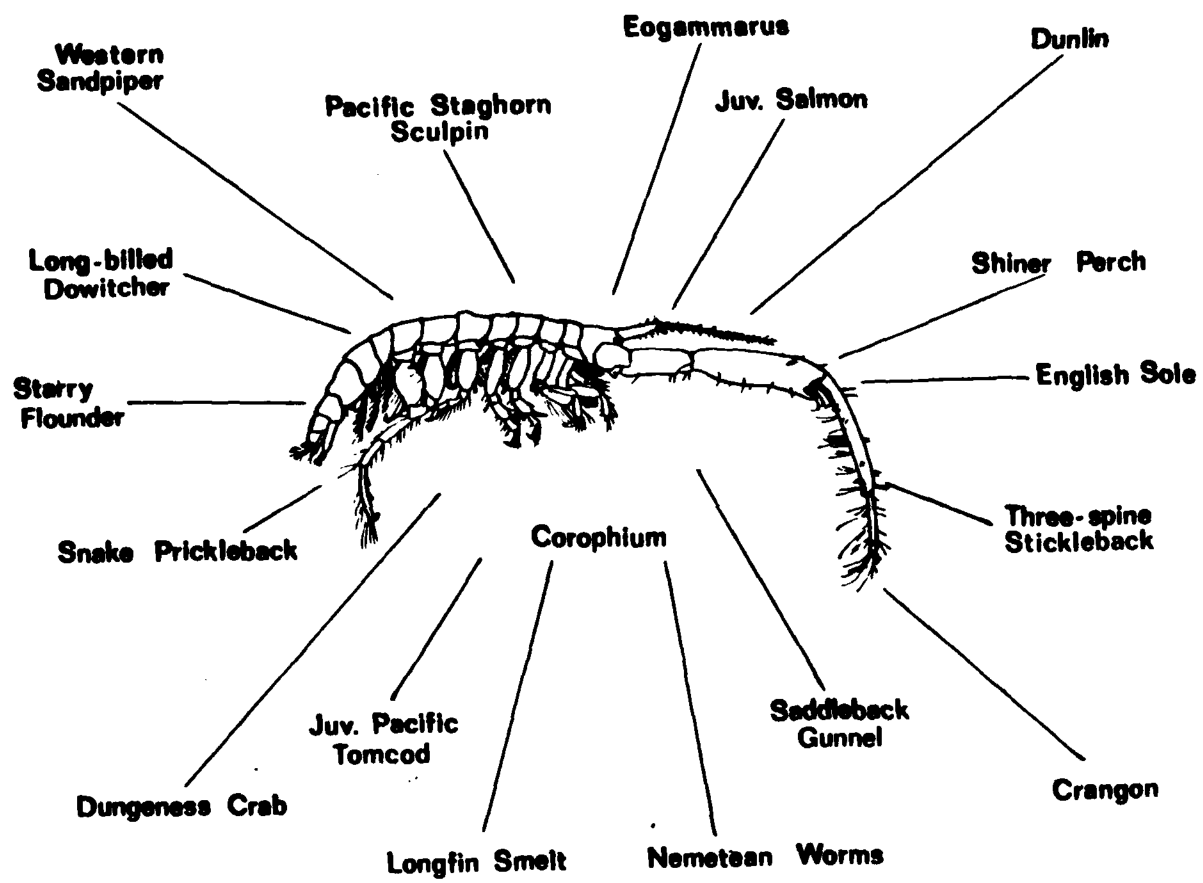

Figure 10: Predators of <u>Corophium</u> <u>salmonis</u>.

This study, along with the work of Casabianca (1975) and Birklund (1977), suggests that the dredging of the main navigation channel proposed in the widening and deepening project may have a significant impact by reducing the population of another species of Corophium, C. spinicorne, which is abundant in the Cosmopolis area. Densities of greater than 60,000 C. spinicorne per m^2 occur in this area (Albright and Bouthillette, 1981). If production of C. spinicorne is comparable to that of C. salmonis, dredging activity in the Cosmopolis portion of the navigation channel will result in a tremendous impact to the predators of C. spinicorne, particularly chinook salmon (C. Simensted, pers. comm.[1], 1981), through reduction of the food resource. This should be an area of primary concern if any further studies are conducted related to widening and deepening of the navigation channel, as dredging and the creation of a turning basin just downstream of Cosmopolis will affect a large percentage of the C. spinicorne habitat present in Grays Harbor.

[1]School of Fisheries, WH-10, University of Washington, Seattle, WA, 98195

SUMMARY

1. To successfully assess impacts resulting from widening and deepening of the navigation channel in Grays Harbor, it is important to determine the quantity of food resources available to important predators. Corophium salmonis is a dominant benthic member of the mudflat community in Grays Harbor and an important food organism for many commercially and recreationally important species.

2. Intertidal populations of C. salmonis were sampled at two elevations (+1.8 and +.6 meters relative to MLLW) at each of two sites; Site M was a proposed salt marsh establishment site and Site MC a control area.

3. Samples collected during spring and summer of 1980 were used to determine the abundance, biomass, population structure, growth rate, and production of C. salmonis. Numbers of C. salmonis at the +.6 meter station at Site MC were so few that data from this station were excluded from further analysis.

4. Abundances at the remaining three stations ranged from 216 to 49,700 C. salmonis per m^2, and were highest at the +1.8 meter stations. Peak abundances occurred during July at both the 1.8 meter stations and during August at the .6 meter station at Site M. The 1.8 meter station at Site MC had a higher abundance of C. salmonis than the 1.8 meter station at Site M during spring, while during summer abundances at the 1.8 meter station at Site M were highest.

5. Female C. salmonis reached sexual maturity at a length of 4.0 - 4.5 mm. Brooding of eggs began in April and continued through the end of September when sampling was terminated. The mean number of eggs per brood was 11.4 during spring; however this figure must be considered a low estimate as

some eggs were lost from the brood pouch during sample preservation and processing. Eggs were brooded for 2-3 weeks during spring.

6. Male-female ratios were considerably lower for sexually mature C. salmonis than for immature individuals. This appears to result from a high rate of predation on sexually mature males, which leave their tubes in search of sexually mature females. Male-female ratios of mature C. salmonis were lower at the .6 meter station at Site M than at either 1.8 meter station. Ratios were lower during summer than spring. Male-female ratios for immature C. salmonis were inversely proportional to ratios for sexually mature individuals, suggesting a possible genetic response that increases male-female ratios when it became excessively low for adults.

7. Samples of both natural populations and cohorts artificially isolated inside in situ growth cages were used to determine rates of growth. Size-specific growth rate curves and biomass data were used to compute C. salmonis production.

8. Total C. salmonis production at each station for the period April 1 to September 30 varied from 3.6 to 10.7 grams per m^2. Corophium production was significantly higher at the 1.8 meter stations than the .6 meter station. The 1.8 meter stations at Sites M and MC had comparable Corophium production values, but because of the small number of C. salmonis at station .6 MC, it is felt that Site M had higher C. salmonis production when both the 1.8 and .6 meter stations were combined than Site MC.

9. Turnover rates (the ratio of production to mean biomass) varied from 7.2 to 8.6, indicating that the amount of organic matter available to predators of C. salmonis is much higher than mere estimates of biomass would indicate.

10. Little impact to *C. salmonis* populations are expected from dredging activities related to the widening and deepening of the navigation channel in Grays Harbor.

11. Another species of *Corophium*, *C. spinicorne*, occurs in densities of up to 60,000 per m^2 in the main navigation channel near Cosmopolis. If the production of *C. spinicorne* is comparable to that of *C. salmonis*, dredging may adversely affect *C. spinicorne* populations. Predators which use *C. spinicorne* as a food resource, such as chinook salmon, may consequently be affected.

12. Disposal of dredged materials on intertidal tideflats, such as at the proposed salt marsh establishment site, would impact *C. salmonis* populations and its predators, especially on a short term basis. The impact may be partially or fully offset by increased primary production if a salt marsh were successfully created upon the disposed dredged materials.

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APPENDIX A

SUMMARY OF PROCEDURES FOR SEDIMENT SAMPLE ANALYSES[1]

Grain Size Analyses

Each sample was allowed to thaw and then subsampled. A 10-15 gram subsample was taken from the inside of the core by slicing it lengthwise with a spatula. Each subsample was then split into a >62μ fraction and a <62μ fraction by wet sieving. The coarse fraction was dried in the oven overnight and then sieved into gravel (>2000μ), coarse sand (2000-500μ), and fine sand (500-62μ) components. The fine fraction was separated into silt (62 to 4μ) and clay (<4μ) components by pipette analysis. These procedures are well described by Krumbein and Pettyjohn (1938).

Volatile Solids

The method of analysis was adapted from "Standards Methods for the Examination of Water and Wastewater," 14th Edition, APHA, AWWA, and WPCF, Washington, D.C., 1975, pp. 96-98. An outline for the procedure follows:

1. Subsamples were taken from partially thawed samples with a number 4 corkborer and placed in preignited and preweighed crucibles. Samples that contained gravel required more complete thawing and were more difficult to accurately subsample.
2. The samples were dried overnight at 103°C, cooled in a dessicator, and weighed.
3. Volatile solids were determined by mass loss following ignition in a muffle furnace at 550°C for one hour.

[1]Analysis performed by Drs. J.B. Phipps and E.D. Schermer of Grays Harbor College, Aberdeen, Washington, 98520

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